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The Lake Erie Program: Monitoring Fish Stock Changes Over Years

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THE LAKE ERIE PROGRAM:
MONITORING FISH STOCK CHANGES
OVER YEARS

by

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ABSTRACT

The Lake Erie Fisheries Program of the Ontario Ministry of Natural Resources used a stratified sampling design with partial replacement of catch stations from 1987 to 1990 to monitor the fish community. Estimation methodology associated with partial replacement sampling design based on double sampling regression estimates was not suitable for the small sample sizes encountered and for multivariate descriptive study.

An unbiased estimation methodology for detecting changes and for descriptive study has been developed for two or more sampling occasions in either a simple or a stratified statistical population. The methodology for two occasions links well known cases in statistical inference theory, such as the Student t-test, the Satterthwaite t-test and the paired t-test, in a single inference procedure where the previous tests are specific cases. For more than two occasions, the methodology links well known oneway anova between years (independent samples) and the two-way anova with one replicate per cell of a "year by unit" design (paired samples) in a single inference procedure where the preceding tests are specific cases. Rules for the computation of degrees of freedom for inference are suggested.

A Principal Component Analysis is also suggested to determine principal components with related patterns of change, habitat influences as well as other correlated patterns in the observations. The technique is based on the standardization of the covariance matrix with the sampling variances associated with the estimation methodology developed. This technique is compared with PCA on covariances and on correlations.

The suggested estimation methodology and PCA are applied to Lake Erie fish populations monitored in the area of the lake under study over the 1987-90 period.

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Jim presented me first to Brian A. Henderson at Maple and later, I met Stephen J. Nepszy at the Lake Erie Fisheries Station at Wheatley. They were the designers for the Lake Erie Program. Brian has been fully cooperative, while Steve has provided lots of field insights. My proposal at that time was concerned with correlations but a shift occurred (action of a strange attractor ?!?) to match my concerns directly to the underlying sampling problems of the Lake Erie Program. Brian and Steve are from those that cannot be forgotten in the acknowledgments when the final word is coming.

I would also like to thank the crew of anonymous captains and field technicians who collected the data, without which no research could have been undertaken.

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INTRODUCTION

Management problems associated with fisheries assessment of large ecosystems shared by many juridictions such as the Great Lakes were discussed recently in Christie *et al.* (1987a) and Christie *et al.* (1987b). Variability in the measurement of the catch of fish by the commercial fishery, difficulties in the estimation of sport catches, calibration of fishing effort, accuracy of the measures, and the use of local sampling designs (transect sampling designs for example) limit the possibility of coherent assessment. The need for a versatile assessment program that allows continuity of observation through time with standard measures was implicitly stated.

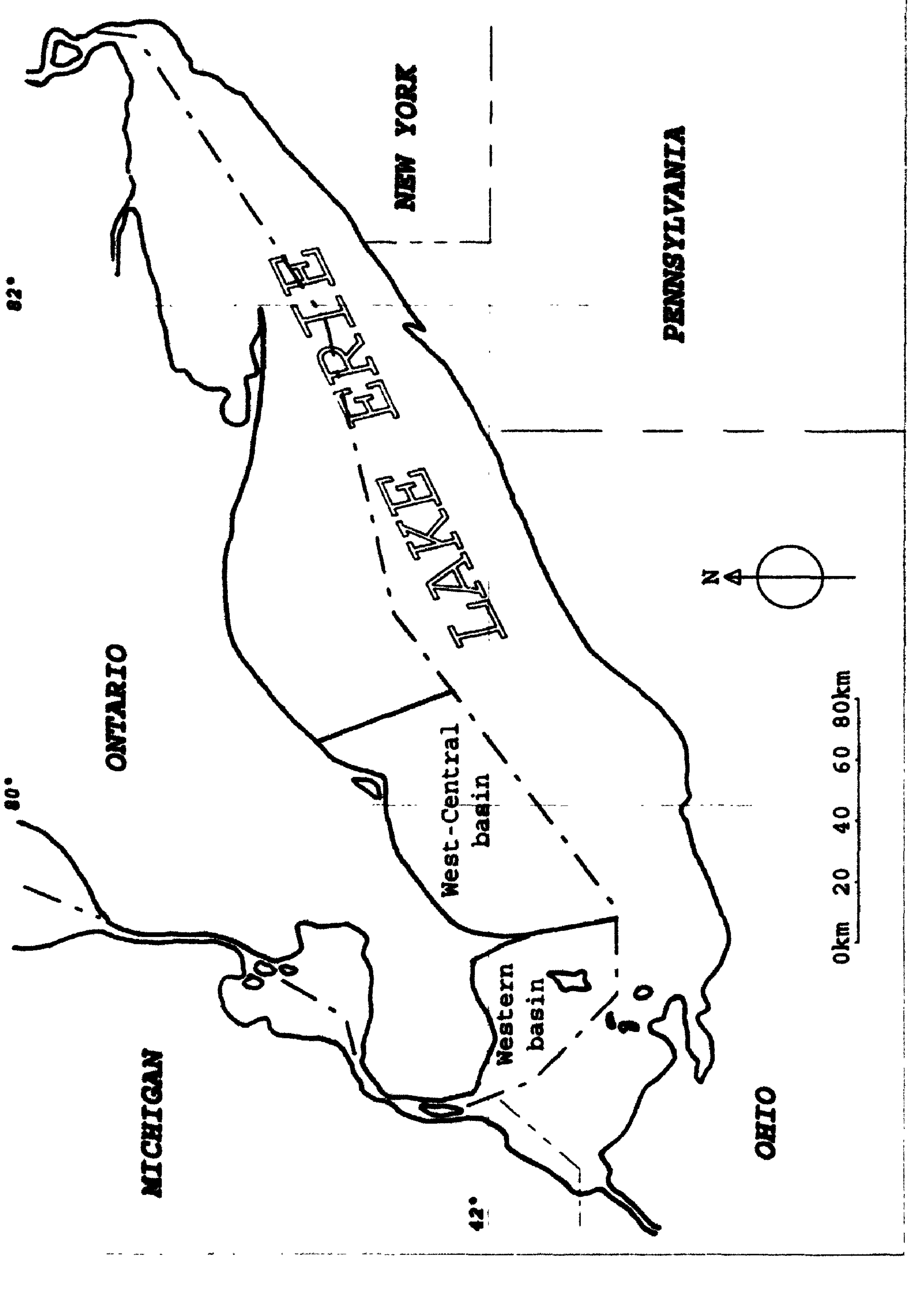
The Lake Erie Fish Community Program was initiated in 1987 by the Fisheries Research Branch of the Ontario Ministry of Natural Resources. A major objective of the program was to derive estimates of annual relative abundance for the fish populations and to monitor changes over years in relative abundance. The program was designed to provide unbiased estimates of the relative abundances by randomly selecting sampling sites in the lake. These estimates would then be compared with results of assessment programs by other agencies and with estimations based on commercial fishery statistics.

The program was designed to monitor the fish stock in two statistical districts of the Ontario part of Lake Erie shown in Figure 1. The Western basin and the West-Central basin are delimited in the lake by the Canada-USA border, and are located in the west part of the Lake Erie.

The division of the lake into statistical districts is a first level of stratification that allows comparable data to be combined with stratification weights in annual descriptive analysis. Stratification also allows the use of different sampling techniques within different statistical districts. In this program, a second level of stratification was defined with respect to depth in the two basins. The variance estimates of relative abundances within the strata would then be decreased since depth stratification would more or less target homogenous environment in the ecosystem structure.

A sampling design over years was set in each of these basins with a particular pattern. In order to monitor change in fish abundances, a set of fixed catch stations should have been the appropriate choice over years (Cochran 1977) but at the cost of loss of generalization. Any catch station may have a unique trend not reflected by other stations. Keeping such station, selected initially by chance, fixed over years may not be representative of the evolution over years in the area of the lake under study. The usual alternative to fixed catch stations is a complete replacement of the catch stations. This

Figure 1. Location of the area under study.



alternative loses the consistency in the comparison provided by fixed catch stations and, consequently, is less suitable for the program. The sample structure adopted was a mixture of both approaches. From the previous year sample of locations, some are kept and the current sample is completed with new catch stations. This is called a sampling design over successive occasions with partial replacement. The matched stations between two years bear testimony to the possible changes occuring between years and the unmatched stations increase the possibility of generalization of the results.

The sampling design over successive occasions of partial replacement was described first by Jessen (1942). This estimation methodology has been considered by several investigators who improved the basic methology within a general univariate theory. Such improvements include specific correlation pattern between years (Yates 1981, Patterson 1950, Hansen *et al.* 1955, Tikkiwal 1960, Ware *et al.* 1962, Prabhu-AjgaonKar 1968, Singh 1968, Cunia *et al.* 1969, Lowerre 1979, Tikkiwal 1979, Agrawal 1984, Scott 1984 and Sisodia 1985), multi-stage sampling (Tikkiwal 1964, Singh *et al.* 1969, Kathuria 1975, Tikkiwal 1979, Agarwal *et al.* 1980, Jain 1981 and Omule 1984), sampling with varying probabilities (Des Raj 1965, Ghangurde *et al.* 1969, Chotai 1974 and Arnab 1979), rotation sampling (specific case of sampling with partial replacement, Eckler 1955, R o *et al.* 1964, Manoussakis 1977, Wolter 1979 and Cantwell 1990), optimal allocation (Jessen

1942, Patterson 1950, Kulldorff 1963, Ghangurde *et al.* 1969, Sen 1973, Hazard *et al.* 1974, Kilpatrick 1981, Omule *et al.* 1982a and Tripathi 1988), models for proportions (Hazard 1977) and multivariate considerations or auxiliary information (Cunia 1965, Sen 1973, Newton *et al.* 1974, Omule *et al.* 1982b, Okafor 1987, Houllier 1992).

It is uncommon to find fishery studies using such a design. Applied biological fields that use more and more the sampling design with partial replacement are agriculture (Chhikara *et al.* 1984 and Chhikara *et al.* 1992) and Forestry. In Forestry, the methodology has been integrated and developed with practical considerations (Ware *et al.* 1962, Cunia 1965, Cunia *et al.* 1969, Newton *et al.* 1974, Omule 1984, Scott 1984, Schreuder *et al.* 1987, Houllier 1992). Recent contributions overlook general consideration of the design and very specific field topics are now considered (Cunia *et al.* 1985, Van Deusen 1989 and Van Deusen 1993). Sampling designs with partial replacement has been adopted in agricultural and forestry sciences because they are well adapted for the management of a resource in a geographical setting.

One important characteristic of the estimation methodology is to provide an adjusted estimate of the mean at a later occasion by combining two independent estimates: a double sampling regression estimate from the matched portion of the samples and a mean estimate from the unmatched portion of the samples. Appropriate work for the underlying designs of the Lake Erie Program is given by Scott (1984) who resolved some estimation problems in the earlier work of Ware *et al.* (1962), Cunia (1965) and Cunia *et al.* (1969) in Forestry.

There are two problems with the estimation methodology presented. One, since the first estimate is derived from regression, it induces bias as the sizes of samples involved become small (Sisodia 1985). The best that such methods based on a regression estimate could achieve is to be asymptotically unbiased as the sample sizes become larger. The second problem comes from the lack of adjustment for the estimation of the total variance or covariance for uses in descriptive analyses such as Principal Component Analysis.

These problems are negligible when the aim of the study requires only estimates such as mean productivity per hectare, or when the study is done by large-scale human surveys, or inventory by satellite imagery of the territory (Chhikara *et al.* 1984) where the sample sizes are large. However when each individual measurement is obtained by an expensive process and the study of the relationships between variables is important, these problems become quite acute.

This thesis provides unbiased estimators of change in abundance and related unbiased sampling variances and unbiased estimators for descriptive analysis when a partial replacement sampling design in a simple or a stratified population is applied. This thesis also presents a method of monitoring fish population by deriving principal components of change in a complex data set.

Structure of this thesis

The first chapter of this thesis describes the M.N.R. Lake Erie Program from a sampling and methodological point of view over the period 1987 to 1990. The sampling unit, the schedule of sampling and the measure of counts of fish from different mesh size panels of gillnets are presented. Choice of a basic mathematical transformation for the counts is made in a context of a specific model of catch and with some descriptive information from the data base. Reliability of the measures is discussed.

In the second chapter, new estimators of change in abundance are described. These estimators are presented in order of their complexity. First, a set of estimators for change between two occasions is elaborated, followed by a general case for two or more occasions in a simple population. The two cases are adapted to the case of a stratified population. Finally, stratified estimators are presented for descriptive analyses, that take into account the partial replacement structure of the samples.

In the first section of the third chapter, the inferential procedures developed to monitor fish stock changes over years, using the estimators presented in the second chapter are described. In the second section, a method of standardization of the covariance matrix in Principal Component Analysis is presented. This method allows better discrimination of change over years on the most important principal components than would do the usual PCA with the covariance or correlation matrix.

The fourth chapter presents results based on the inference and analysis procedures developed in chapter three. In the fifth chapter, the new PCA analysis is compared to traditional PCA methods. The status of all species showing statistical change during the study are discussed. Principal trends of change are summarized. The sampling methodology is discussed.

1. Description of the Lake Erie Fish Community Program

1.1 Unit of observation

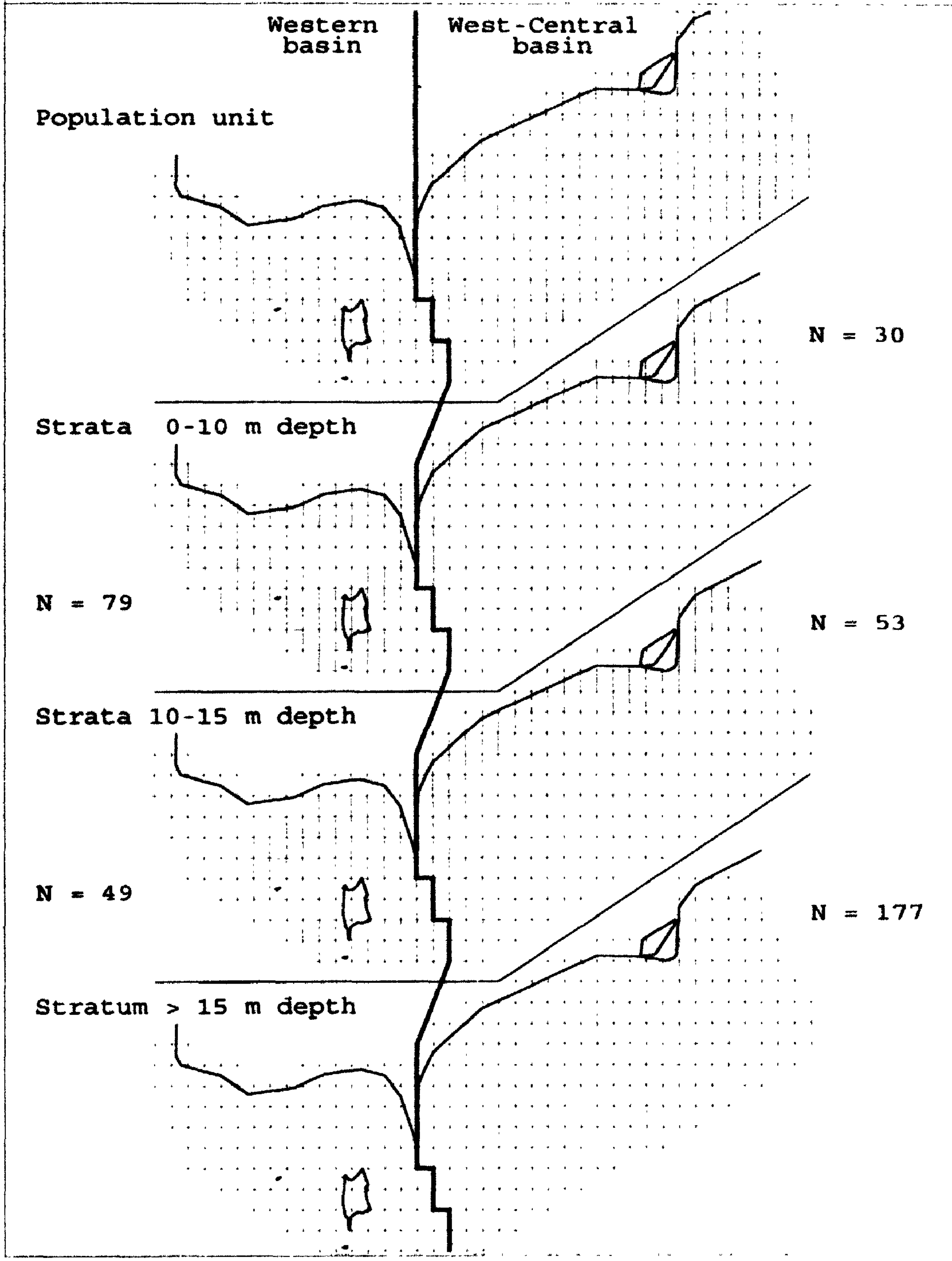
During the four consecutive years (1987-1990) of the Lake Erie Program - OPEN LAKE SAMPLING PLAN, fish population levels were assessed by a sampling scheme using a catch station as the unit of observation and the gillnet as a measurement device which provided counts of caught fish.

Catch stations were established with a grid from two basins in the lake: the Western basin and the West-Central basin (Figure 1). A catch station was defined by a rectangle on a map delimited by 2.5 longitudinal minutes and 2.5 latitudinal minutes as shown in Figure 2.

1.2 Sampling strategies

The basins were split into depth strata, and catch stations were randomly selected from the available stations within each stratum. The catch stations are presented in Figure 2 by basins and depth stratification. The common justification for a stratified design is that within stratum variance estimate is generally smaller when the stratification is adequately designed with respect to the variable of interest than if the entire population was structured in a single set. The stratified estimates are more precise than those from a simple random sampling design. The stratification

Figure 2. The catch station (population unit), the basins and the depth strata in the area under study.



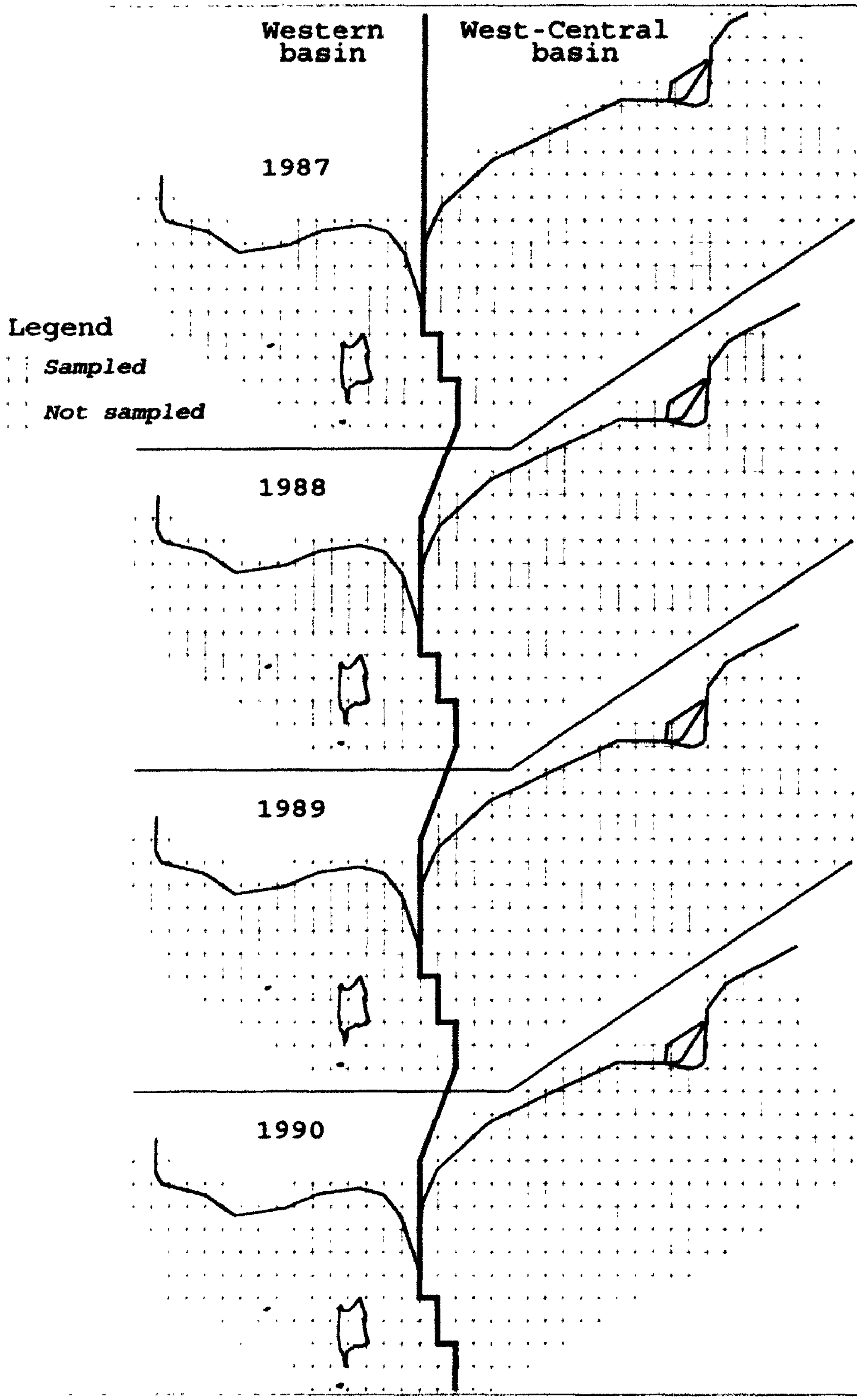
chosen was defined as 0-10 meters depth, 10-15 meters depth and more than 15 meters depth. Depth is known to correspond to a biological gradient in fish populations. Depth would usually create a kind of spatial correlation between the stations and would be reduced by stratification. Deep stations are more likely to show great similarities (highly correlated in their fish density levels) within the entire lake scope, as well as among shore stations. Within a depth stratum, the stations that were relatively similar within the entire lake will more likely exhibit their differences instead of their similarities.

A partial replacement sampling design over years has been adopted to reach both internal validity (internal comparison between years provided by the paired stations) and external validity (generalization and inference not based on the same stations year after year). In setting the next year's sample for each stratum, a random subset of the previous sample is kept and a set of new random stations completes the next years sample. This leads directly, on average, to an increase of the proportion of visited catch stations over time as well as an increase of the proportion of catch stations visited twice and more (paired stations). The number of stations studied and revisited are reported in Table 1. Also, Figure 3 shows the locations of the sampled catch stations in the lake for each year of the study.

Table 1. Description of the available, studied and revisited stations from 1987 to 1990 in the Lake Erie Program.

stratum	Number of stations available N	Number of stations studied (% of N)	size (n) of samples 1987	1988	1989	1990	Total number of records	Number of revisited stations (% of N)
Western basin								
stratum 0-10m	79	27 (34.2%)	10	8	10	10	38	10 (12.7%)
stratum >10m	49	22 (44.9%)	5	12	10	9	36	8 (16.3%)
West-Central basin								
stratum 0-10m	30	17 (56.7%)	9	9	10	9	37	10 (33.3%)
stratum 10-15m	53	15 (28.3%)	5	4	5	5	19	3 (5.7%)
stratum >15m	177	33 (18.6%)	10	12	10	11	43	8 (4.5%)
Total	388	114 (29.4%)					173	39 (9.8%)

Figure 3. The catch stations sampled during 1987 to 1990 in the area under study.



From 79 available catch stations in the 0-10m depth stratum of the Western basin, 27 (34.2 %) have been visited in at least once in the study. These 27 catch stations provided 38 year-records of data since a given station may have been visited during more than one year. A set of 10 stations that represent 12.7 % of the stratum was revisited two or more times. The overall percentage of visited stations was 29.4% and varied from 18.6% to 56.7% between the five basin-strata. The overall percentage of revisited stations was 9.8% and again varied from 4.5% to 33.3%.

1.3 Sampling schedule

The catch program began each year around mid-April. Many species are in their post spawning period. Figure 4 presents the Julian day schedule of sampling at all visited catch stations. The schedule for the four years in each basin is also summarized in Table 2.

The sampling has been done from west to east, with no overlap between basins except for one year (1989). This may cause some problems when the data of the two basins are combined to provide overall estimates. The period of sampling in the Western basin varies from 18 to 30 days and from 20 to 36 days in the West-Central basin. With these ranges of time for sampling and the starting dates of sampling, the estimations would be comparable from one year to another

Figure 4. Schedule of sampling in Julian day of each catch station in the two basins for each year under study.

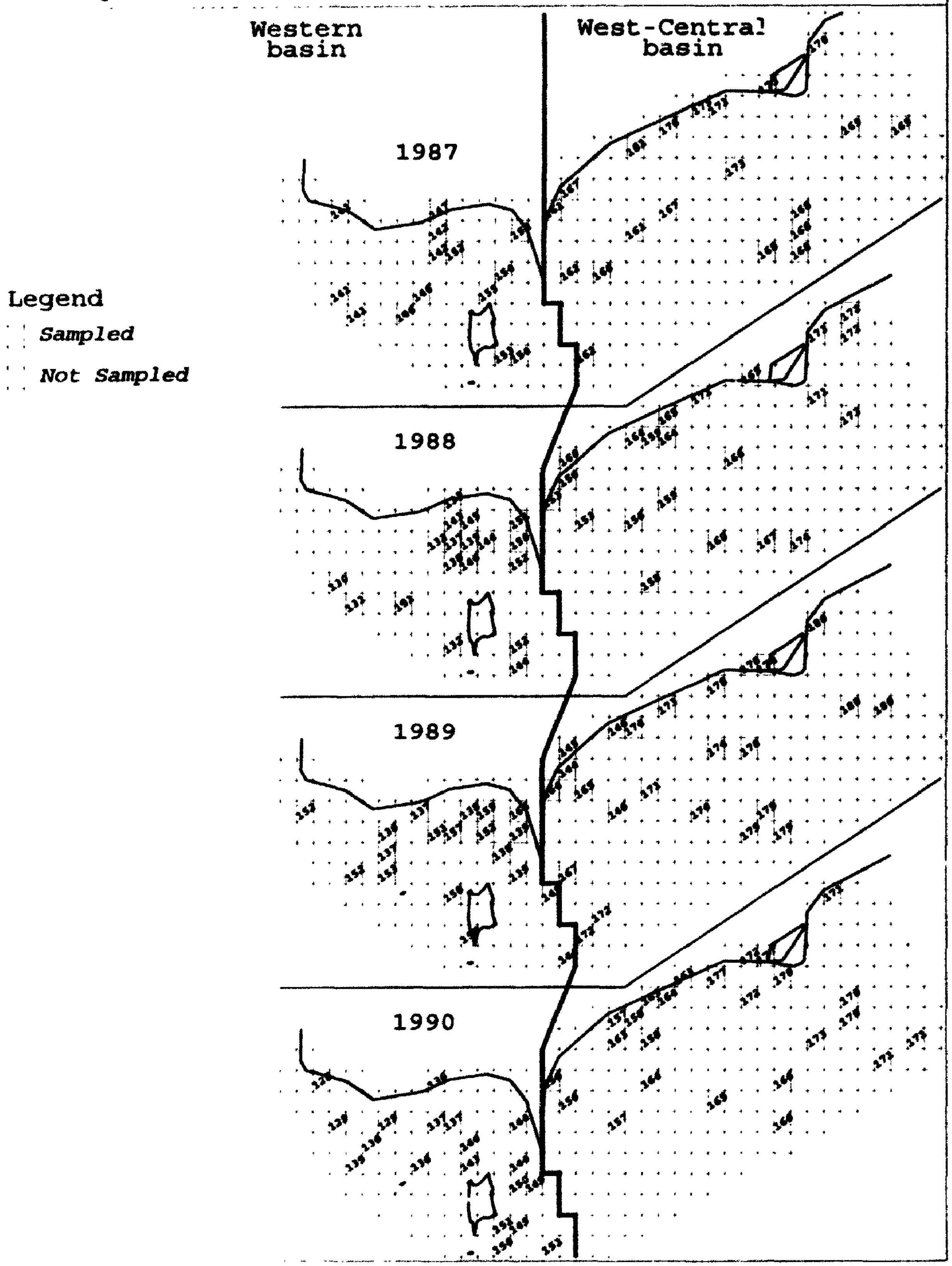


Table 2. Julian dates of the catch period at each year in the two basins.

Basin	Year	Starting date	Ending date	Range (in days)	Average
Western					
	1987	141	159	18	148.3
	1988	130	152	22	141.6
	1989	136	166	30	147.4
	1990	128	151	23	141.0
West-Central					
	1987	161	181	20	169.9
	1988	153	174	21	164.0
	1989	144	180	36	169.8
	1990	156	177	21	166.0

within a given basin, provided that the spawning behaviour and species movements would be covered year after year in the same manner. The relative abundances between the basins may be affected by the species behaviour in spring. The patterns of fluctuation in abundance is not the same in early and late spring. Hence, there is a need to split the data into separate sets for the two basins.

1.4 Measure of the relative abundance

Gillnets were installed on the bottom of the lake for one night. They were then lifted and brought back to the fishery station for counting.

The gear was a graded multifilament nylon gillnet and was structured into panels of 12 different mesh sizes from 32mm to 127mm randomly alternated in order to track different sizes and age classes of fish. The gillnet is a passive fishing device and its efficiency and selectivity may change from species to species due to complexity of behaviour and morphological differences. Henderson *et al.* (1991) worked out on the selectivity of the gillnet panels for walleye for the two basins from 1978 to 1989. It is not possible to adjust for all species caught during the study. Modifying the catches for selectivity for some species would alter the integrity of the measures between species. As a result, adjustments were not made.

The species counts are recorded by mesh size. The different mesh sizes are able to catch more or less specific sizes of fish (asymmetric bell shape with a peak (Henderson *et al.* 1991)). An individual of a species caught by a small mesh size panel is generally smaller than ones caught by larger mesh size panels. Data for fish length and age classes were available from the catch records. However, these topics were not treated in the present thesis because the fish length is a variable measured on the variable of the catch station, as well as the age of the fish. This second hierarchical level of variable is not treated here and could itself be a major project. Nevertheless, the mesh size is a fairly good proximate measure of the size of the fish and is adequate for assessment of year structure. This choice will be discussed in the last chapter in the assessment over time scope.

Over the four years of catch, 38 species of fish were found in the 173 catch records. The list of these species sorted by relative importance in the catch is reported in Table 3. The common, scientific and French names and the abbreviation of the species name that will be used in other tables are given.

The species were caught in panels of 12 different mesh sizes and provide a total of 204 different species-mesh variables for the analyses. Table 4 shows the abundances (counts per length of panel) during the four years of the 38 species cumulated by each mesh size panel and reports the relative importance in the total catch of each species. The white perch, the yellow perch, the freshwater drum, and the alewife cumulate almost 95 % of the total catch. The walleye, the white sucker, the rainbow smelt and the white bass complete the cumulative 99 % total abundance.

Since the nets were in the water about a day, counts are cumulative counts over one day. Hence, even if two species are strongly positively correlated, it may not indicate their interdependence (competition, predator-prey relationship, ...). It may mean that they have used the same location and were caught during the same day. Many hours may separate the two events, and their orders are unknown. On the other hand, a negative correlation has a more concrete meaning. It would indicate that one species was there when the other was not.

Table 3. Common and scientific names of species caught by gillnet during the study (sorted from high to low relative total abundance) and abbreviations used in the thesis.

Common english name	Abbreviation	Scientific name[1]	2Nom français[2]
white perch	WPer	*Morone americana* (Gmelin)	Bar-perche
yellow perch	YPer	*Perca flavescens* (Mitchill)	Perchaude
freshwater drum	FreD	*Aplodinotus grunniens* (Rafinesque)	Malachigan
alewife	Alew	*Alosa pseudoharengus* (Wilson)	Gaspareau
walleye	Wall	*Stizostedion vitreum* (Mitchill)	Doré
white sucker	WSuc	*Catostomus commersoni* (Lacepède)	Meunier noir
rainbow smelt	RaSm	*Osmerus mordax* (Mitchill)	Eperlan Arc-en-ciel
white bass	WBas	*Morone chrysops* (Rafinesque)	Bar blanc
silver chub	SiCh	*Hybopsis storeriana* (Kirtland)	Mené à grandes écailles
spottail shiner	SpSh	*Notropis hudsonius* (Clinton)	Queue à tache noire
troutperch	Trpe	*Percopsis omiscomaycus* (Walbaum)	Omisco
gizzard shad	GSha	*Dorosoma cepedianum* (Lesueur)	Alose à gésier
channel catfish	ChCa	*Ictalurus punctatus* (Rafinesque)	Barbue de rivière
smallmouth bass	SBas	*Micropterus dolomieui* (Lacepède)	Achigan à petite bouche
rock bass	RBas	*Ambloplites rupestris* (Rafinesque)	Crapet de roche
burbot	Lota	*Lota lota* (Linnaeus,	Lotte
northern redhorse sucker	NRSu	*Moxostoma macrolepidotum* (Lesueur)	Suceur rouge
lake whitefish	LaWh	*Coregonus clupeaformis* (Mitchill)	Grand Corégone
coho salmon	Coho	*Oncorhynchus kisutch* (Walbaum)	Saumon Coho

[1] Robins *et al.* 1991.
[2] Scott *et al.* 1974.

(continued)

(Table 3.continued)

Common english name	Abbreviation	*Scientific name*[1]	Nom français[2]
stonecat	Ston	*Noturus flavus* (Rafinesque)	Barbotte des rapides
emerald shiner	EShi	*Notropis atherinoides* (Rafinesque)	Mené Emeraude
quillback	Quil	*Carpiodes cyprinus* (Lesueur)	Couette
brown bullhead	BBul	*Ameiurus nebulosus* (Lesueur)	Barbotte brune
bowfin	Bowf	*Amia calva* (Linnaeus)	Poisson-castor
golden redhorse	GoRe	*Moxostoma erythrurum* (Rafinesque)	Suceur doré
tadpole madtom	TaMa	*Noturus gyrinus* (Mitchill)	Chat-fou brun
yellow bullhead	YBul	*Ameiurus natalis* (Lesueur)	Barbotte jaune
carp	Carp	*Cyprinus carpio* (Linnaeus)	Carpe
lake trout	LaTr	*Salvelinus namaycush* (Walbaum)	Touladi
lake sturgeon	LaSt	*Acipenser fulvescens* (Rafinesque)	Esturgeon de lac
unknown721	U721	MNR species 721	Unknown721
unknown802	U802	MNR species 802	Unknown802
fantail darter	FaDa	*Etheostoma flabellare* (Rafinesque)	Dard barré
white crappie	WCra	*Pomoxis annularis* (Rafinesque)	Marigane blanche
sauger	Saug	*Stizostedion canadense* (Smith)	Doré noir
rainbow trout	RaTr	*Salmo gairdneri* (Richardson)	Truite arc-en-ciel
mottled sculpin	MoSc	*Cottus bairdi* (Girard)	Chabot tacheté
northern pike	NPik	*Esox lucius* (Linnaeus)	Grand Brochet

[1] Robins *et al*. 1991.
[2] Scott *et al*. 1974.

Table 4 - Total abundances of species caught by 45,7m of gillnet panels of different mesh sizes during the study.

Common names	Mesh size (mm) of gillnet panels					
	32[1]	38[1]	45[1]	51	57	64
white perch	1191	1182	2266	10476	10985	10051
yellow perch	2590	2265	3337	6892	2395	1492
freshwater drum	20	17	34	416	670	1133
alewife	190	455	319	129	26	32
walleye	19	21	45	169	230	285
white sucker	1	0	0	18	33	59
rainbow smelt	43	43	44	97	123	87
white bass	10	17	36	48	55	97
silver chub	25	37	43	37	4	0
spottail shiner	95	15	1	0	0	0
troutperch	40	5	0	0	0	0
gizzard shad	0	0	0	0	2	2
channel catfish	0	0	1	3	4	3
smallmouth bass	0	0	0	0	0	3
rock bass	1	0	1	1	7	9
burbot	0	1	0	1	1	0
northern redhorse sucker	0	0	0	0	1	3
lake whitefish	0	0	0	0	0	0
coho salmon	0	0	2	1	3	0
stonecat	0	1	0	0	2	1
emerald shiner	2	0	0	0	0	0
quillback	0	0	0	0	1	0
brown bullhead	0	0	0	1	0	3
bowfin	0	1	0	0	0	0
golden redhorse	0	0	0	0	0	0
tadpole madtom	0	0	0	2	1	0
yellow bullhead	0	0	0	2	1	1
carp	0	0	0	0	0	0
lake trout	0	0	0	0	0	0
lake sturgeon	0	0	0	0	0	0
unknown721	0	0	0	0	0	0
unknown802	0	0	0	0	0	0
fantail darter	0	0	0	0	0	0
white crappie	0	0	0	0	0	0
sauger	0	0	0	0	0	0
rainbow trout	0	0	0	0	0	0
mottled sculpin	0	0	0	0	0	0
northern pike	0	0	0	0	0	0

[1] Panels of 13,7 m length instead of 45,7m. These counts are standardized to 45,7m when needed in analysis.

(continued)

(Table 4 continued)

Common names	Mesh size (mm) of gillnet panels 70	76	89	102	114	127	Abundance %	cum %
white perch	8504	6108	2295	392	96	52	53.309	53.3
yellow perch	578	198	73	29	12	7	32.258	85.6
freshwater drum	1445	1501	1236	815	311	157	6.554	92.1
alewife	8	22	9	4	7	4	2.858	95.0
walleye	308	245	158	221	123	80	1.740	96.7
white sucker	86	165	219	260	138	28	0.835	97.6
rainbow smelt	63	73	40	23	13	10	0.769	98.4
white bass	81	106	55	39	12	1	0.583	98.9
silver chub	0	0	1	0	0	1	0.325	
spottail shiner	1	0	0	1	0	0	0.308	
troutperch	0	0	0	0	0	0	0.124	
gizzard shad	0	6	13	18	22	18	0.067	
channel catfish	6	6	6	14	12	4	0.051	
smallmouth bass	5	4	8	7	16	3	0.038	
rock bass	4	3	8	1	0	0	0.033	
burbot	0	2	5	7	9	10	0.032	
n. r. sucker	0	1	3	10	4	1	0.019	
lake whitefish	0	2	1	2	4	2	0.009	
coho Salmon	0	0	0	0	0	0	0.009	
stonecat	0	2	0	0	0	0	0.007	
emerald shiner	0	0	0	0	0	0	0.006	
quillback	1	1	3	0	0	0	0.005	
brown bullhead	0	1	1	0	0	0	0.005	
bowfin	0	0	0	1	0	0	0.004	
golden redhorse	0	0	2	0	0	2	0.003	
tadpole madtom	1	0	0	0	0	0	0.003	
yellow Bullhead	0	0	0	0	0	0	0.003	
carp	0	0	0	1	1	1	0.002	
lake trout	1	0	0	1	1	0	0.002	
lake sturgeon	0	0	0	0	1	1	0.002	
unknown721	0	0	0	2	0	0	0.002	
unknown802	0	0	0	2	0	0	0.002	
fantail darter	0	2	0	0	0	0	0.002	
white crappie	1	1	0	0	0	0	0.002	
sauger	0	0	1	0	0	0	0.001	
rainbow trout	0	1	0	0	0	0	0.001	
mottled sculpin	0	1	0	0	0	0	0.001	
northern pike	1	0	0	0	0	0	0.001	

1.5 Underlying model and the partition of the variation of the fish count

Let us define a population of N units (catch stations) U_j, $j = 1 \ldots N$, on which the quantitative character X_j is attached to each U_j unit. The X_j values in the population have a mean of μ_X and a variance of S_X^2 and let the distribution of X_j be a function of at least these two parameters so that

$$X_j \sim D(\mu_X, S_X^2, \ldots) ;$$

D could be, for example, a normal probability distribution function depending only then on μ_X and on S_X^2.

Let us state that X_j cannot be observed directly due to measurement variability (intrinsic variation linked to the measurement device or process). Instead of X_j, only a value x_j (integer or real) can be measured. x_j is related to X_j by a specific probability distribution such that over many measurements of the value x_j at the same unit U_j and at the same time, provided that the value of X_j is not affected, the expectation over measurements of x_j, $E_m(x_j)$, is the value of X_j, and x_j fluctuates from one measurement to another with a specific variance Φ_j. To be more specific, let this Φ_j be a value which may be a constant for all units, a function X_j or any other functions but restricted by the characteristic that it is fixed for the unit j at that moment.

Let us state the distribution of x_j given that U_j is observed, be a function of at least these two parameters so that

$$x_j \sim M(X_j,\ \Phi_j,\ \ldots\ )\ ;$$

M could be, for example for an integer measure x_j , a Poisson probability distribution, a Negative binomial probability distribution, or for a real measure x_j , a normal probability distribution.

The partition of the components of variation of the observed value x_j is given by

$$x_j = \mu_X + (\ X_j - \mu_X\ ) + (\ x_j - X_j\ )\ ;$$

When a simple random sampling design without replacement is applied to identify a population subset of n units to be visited and when only one measure x_j can be observed per unit sampled, the components cannot be isolated.

Since one of the main interests of sampling a population is to obtain an appropriate estimation of the population mean, it can be shown that the double expectation (expectation over all possible samples and over all possible measurements) of the sample mean of the observed x_j, regardless of D but with to the following M distributions which were studied for this thesis: Poisson, Negative binomial and normal, is equal to

$$E_{sm}(\bar{x}) = \mu_X ;$$

This result indicates that the mean of the observed x_j in the sample is an unbiased estimator of the population mean of X, even if it is measured only once at each unit U_j sampled with measurement variability.

The double expectation of the sample variance of the observed x_j, regardless of the D and with the specified M distributions, is equal to

$$E_{sm}(s_x^2) = S_X^2 + \Phi_0 ;$$

where the first component, S_x^2, is the true variance between the X_j in the population and the second component, Φ_0, which represents the measurement variation, is given by

$$\Phi_0 = \frac{\sum_{j=1}^{N} \Phi_j}{N} ;$$

This result indicates that the variance between the observed x_j in the sample is a biased estimator of the population variance of the true values of X since this variance increases, on average, by a factor related to the variation between measures, the overall mean of the measurement variances at each unit.

The expected variance of the sample mean to the true mean μ_x over sampling and measurement is equal, regardless of the D distribution and with the specified M distributions, to

$$E_{sm}(\,\bar{X} - \mu_X\,)^2 = \left(\frac{1}{n} - \frac{1}{N}\right)S_X^2 \;+\; \frac{\Phi_0}{n}\;;$$

and is equivalent to

$$V_{sm}(\,\bar{X}\,) = V_s(\,\bar{X}\,) \;+\; \frac{\Phi_0}{n}\;;$$

where

$$V_s(\,\bar{X}\,) = \left(\frac{1}{n} - \frac{1}{N}\right)S_X^2\;;$$

is the sampling variance of the sample mean without measurement variation. This term is used in inference procedures underlying the population mean. For example, its square root is the standard error commonly used in the computation of the confidence interval for the population mean.

Thus the variance of the mean of x_j is greater than the variance of the mean of X_j . The variance of the mean of x_j is greater, on average, by a value related to the variation between measures, the overall mean of the measurement variances at each unit divided by the sample size n.

When X_j is the density of a fish species at a point in a lake, the x_j usually represents an integer count of that species. This count is a proximate measure of the density and is obtained by the catch of fish with a gillnet. The count x_j at a point in the lake may vary from 0 to large integer values. Two *M* distributions may describe the variation of x_j at this point over many measurements: the negative binomial distribution with its limiting case, the Poisson distribution. With a negative binomial probability distribution, Φ_j is equal to the value of (X_j + (X_j^2/k_j)), where k_j is a parameter of the negative binomial distribution of the fish (Elliot 1977) that may be specific to a catch station or common for all the catch stations. With a Poisson distribution, where k_j tends to become large, Φ_j is equal to the actual value of X_j . If the x_j distribution is approximately normally distributed given X_j , then Φ_j is equal to the value of σ_j^2 attached to this unit. I will focus on the Poisson and negative binomial distributions which are more appropriate with fish counts.

A mathematical transformation of the fish count may have to be used in order to satisfy some statistical criteria. Statistical tests use the sampling variances computed from the values X_j and implicitly do not take into account the variation that could occur between measurements. The search for a transformation has the objective of obtaining a more or less symmetrical distribution of $Y_j = f(X_j)$, i.e.

approximately normally distributed. Since it has been shown that, on average, the sample variance of the observed x_j and the sampling variance of the observed mean include the variance of interest but also a measurement component, it is possible to ignore this component and use directly the x_j values to search for a transformation. This would be the case if the magnitude of the measurement variability is small compared to the variance between units.

On the other hand, if the measurement variability is large compared to the variance between units, the search for a transformation is directed toward reducing the importance of the measurement component in the variation by making the measurement variability relatively symmetrical for each unit U_j and with the same magnitude of variation for all units. The new (but still unknown) deviation $[\ y_j - Y_j\ ] = f(x_j) - f(X_j) = \epsilon_j$ would almost be symmetrically (and normally) distributed with a measurement variance $\sigma_{\epsilon}{}^{2}{}_{j}$ for each unit.

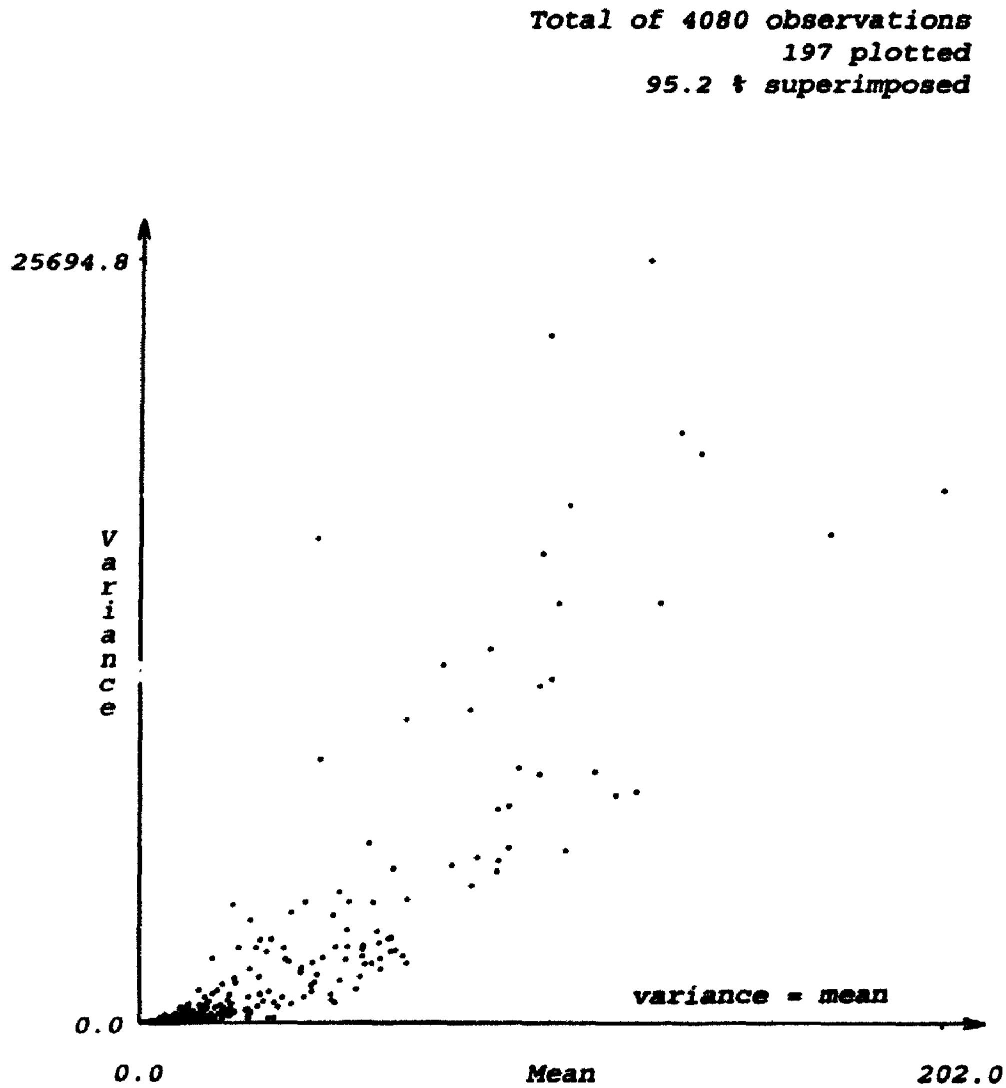
A common approach in ecology is to find transformation of the x_j by BOXCOX or TAYLOR power law procedures (Legendre *et al.* 1984). These procedures produce the expected results when the data come from a unique sampling point. But when these procedures are applied to data that come from many sampling points, they implicitly override the variation between the stations and assume Φ_j equal for all units involved. These techniques are appropriate to transform a *M* distribution of counts at a single point but inappropriate for observations where the D distribution has some non null variance parameter and/or when the M distributions have different variance parameters.

Since there is no formal approach that assesses the variation between units and between measurements when one measure is done at each unit (as expressed in the model), the choice of the transformation is still an empirical decision that greatly depends on the observed distributions of the counts.

Figure 5 shows a plot, from raw counts, of the sample variance against the sample mean for each of the 4080 sample units available (204 species-mesh variables by 5 strata by 4 years) in the data base of the lake Erie program. In this figure it is clear that the sample variance is function of the sample mean.

Between measurements variation (M distribution with Φ_j terms proportional to the X_j and the squared of the X_j) are more likely to be larger then the between units variation (D distribution and S_X^2).

Figure 5. Relation between the sample variance and the sample mean of abundance for all species -separate mesh sizes- and for every year-stratum samples under study.



NB: Scales adjusted for their maximums

As the mean increases, the variance increases much more than the nominal value of the mean (note the "mean=variance" line). Thus the Poisson *M* distribution fails to describe the data and this plot agrees with negative binomial situation where the expected measurement variance is proportional to the average of the ($X_j + (X_j^2/k_j)$) terms in the model. Without prior knowledge of the k_j parameters (that may be specific to each station) a convenient mathematical transformation for a negative binomial process is the $\ln(x_j+1)$ (Elliot 1977). This transformation will be applied to all counts in the data base to obtain more symmetric pattern in the measurement variation and reduction of its importance.

1.6 Reliability of the measure $\ln(x_j+1)$

Six catch stations were measured twice the same day in 1987. Two gillnets were linked together end to end but with sufficient gap to avoid leading. Their catch records have been used here to evaluate the effect of the applied mathematical LOG transformation of the counts specified by $\ln(x_j+1)$.

A reliability coefficient presented by Streiner *et al.* (1989) could have been used to evaluate the effect but this coefficient is based on the repeated measurement of units and the order of the measurement is important. This is not the case in this data subset. The first of the two catches in the data has no special reason to be the first ordered replicate.

The typical reliability coefficient is

$$R = \frac{\sigma_{units}^2}{\sigma_{units}^2 + \sigma_{err}^2} ;$$

and is an estimation of the true variance between units in proportion of the total variance (between units and measurement components). I modified this coefficient after the following observations.

Since the prior model of catch was developed for one measure per unit, it is now possible to have estimates of the true value of X_j and the between measurement component Φ_j . Let

$$y_j = \frac{(x_{j1} + x_{j2})}{2} ;$$

be an estimate of the true value of X_j based on the two measures, and

$$\phi_j = \frac{\sum_{i=1}^{2} (x_{ji} - y_j)^2}{(2 - 1)} ;$$

be the estimate of the measurement variability Φ_j.

The double expectation of the sample variance of the new computed y, regardless of the D and restricted to the following M distributions : Poisson, Negative binomial and normal, is equal to

$$E_{sm}(\ s_y^2\ ) = s_X^2 + \frac{\Phi_0}{2}\ ;$$

which is still a biased estimate of the true variance but where the second component related to the measurement variability is reduced by a factor of 2, the number of repeated measurements at the same unit.

Now, an estimate of Φ_0 is given by

$$\Phi_0 = \frac{\sum_{j=1}^{n} \Phi_j}{n}\ ;$$

An estimator of the true variance of the X_i could be constructed with

$$s_X^2 = s_y^2 - \frac{\Phi_0}{2}\ ;$$

The modified reliability coefficient would then be

$$R = \frac{s_X^2}{s_x^2 + \Phi_0} = \frac{s_X^2}{s_x^2} ;$$

which is the expression of the true variance of the X_j in proportion to the actual variance of the x_j measured once at each unit. It falls between -1, when all the variation would be given by the measurement component, and 1, when there is no measurement variability. The reliability coefficient could have been derived from the sampling variances, but when the finite population correction term is not considered the resulting coefficient is identical to the one derived.

Table 5 and 7 report the reliability coefficients for the raw counts and the log transformed counts of the species-mesh variables encountered at the 6 stations. The ratios of sample variance over sample mean are also reported in Table 6 and 8. Finally, Table 9 compares the reliability of the raw counts and the reliability of the LOG transformed counts.

The coefficients on the raw counts vary from -0.28 to 0.99 and vary among species and among mesh sizes. For the most important species in abundance, the coefficients vary from

Table 5. Reliability measure on the raw counts of fish of different species by mesh size panels observed in 6 stations (3 in each basin) sampled twice at the same day during spring 1987.

	Mesh Size (mm)											
	32	38	45	51	57	64	70	76	89	102	114	127
Species												
WPer	0.13	0.45	0.76	0.72	0.75	0.76	0.77	0.59	0.53	0.17	0.74	0.24
YPer	0.86	0.70	0.50	-0.08	-0.19	0.35	0.25	0.48	0.63	-0.20	-0.09	
FreD	0.00	0.00	-0.25	-0.24	0.29	0.68	0.97	0.69	0.85	0.66	0.08	0.78
Alew	0.80	0.35	0.18	0.32	0.60		0.00	0.00		0.80	1.00	0.00
Wall	0.51	0.60	0.34	0.90	0.99	0.99	0.85	0.34	0.39	-0.12	0.26	-0.28
WSuc					0.23	0.18	0.88	0.18	0.71	0.59	0.15	
RaSm	-0.22	0.29	0.00	-0.09	0.12	-0.20	0.63	0.32	-0.08	0.60	-0.11	0.00
WBas	-0.11	0.80	0.88			-0.11	0.00	-0.11	1.00	0.00	0.00	
SpSh	-0.01											
Tppe	0.34	-0.11										
GSha					0.00			0.00	0.92	-0.10	0.00	-0.02

Table 6. Ratio variance/mean from the raw counts of fish of different species by mesh size panels observed in 6 stations (3 in each basin) sampled twice at the same day during spring 1987.

	Mesh Size (mm)											
	32	38	45	51	57	64	70	76	89	102	114	127
Species												
WPer	287.0	196.8	235.8	273.0	252.9	178.8	200.1	77.2	25.8	13.2	2.0	4.2
YPer	78.2	49.5	71.9	33.4	10.5	3.5	6.2	1.8	0.6	1.3	1.6	
FreD	3.3	6.7	2.7	11.9	5.8	14.7	42.3	27.9	3.7	4.8	4.7	2.7
Alew	51.5	136.1	78.8	22.3	2.4		1.0	1.0		1.6	0.9	1.0
Wall	6.5	7.9	11.9	4.9	12.0	14.6	12.2	4.4	1.2	3.1	2.4	3.6
WSuc					1.3	7.5	2.8	4.5	3.4	1.9	1.5	
RaSm	5.0	3.0	6.7	3.6	5.6	3.5	2.6	2.6	2.0	2.4	0.9	1.0
WBas	3.0	5.2	13.0			0.9	1.0	0.9	0.9	1.0	1.0	
SpSh	18.8											
Trpe	28.5	3.0										
GSha					1.0			3.0	2.4	2.4	4.0	10.0

Table 7. Reliability measure on the LOG transformed counts of fish of different species by mesh size panels observed in 6 stations (3 in each basin) sampled twice at the same day during spring 1987.

	Mesh Size (mm)											
	32	38	45	51	57	64	70	76	89	102	114	127
Species												
WPer	0.61	0.47	0.60	0.68	0.89	0.90	0.62	0.92	0.84	0.37	0.87	0.43
YPer	0.51	0.31	0.61	0.01	-0.29	0.04	0.40	0.40	0.69	-0.23	-0.10	
FreD	0.00	0.00	-0.25	0.01	0.31	0.72	0.78	0.53	0.67	0.38	0.28	0.68
Alew	0.72	0.60	0.51	0.70	0.80		0.00	0.00		0.90	1.00	0.00
Wall	0.66	0.89	0.63	0.63	0.91	0.90	0.82	0.65	0.46	0.06	0.42	-0.35
WSuc					0.35	0.54	0.90	0.59	0.81	0.72	0.16	
RaSm	-0.24	0.19	0.00	-0.17	0.35	-0.23	0.67	0.46	0.03	0.80	-0.11	0.00
WBas	-0.11	0.95	0.98			-0.11	0.00	-0.11	1.00	0.00	0.00	
SpSh	0.14											
Trpe	0.74	-0.11										
GSha					0.00			0.00	0.97	-0.11	0.00	-0.05

Table 8. Ratio variance/mean from the LOG transformed counts of fish of different species by mesh size panels observed in 6 stations (3 in each basin) sampled twice at the same day during spring 1987.

	Mesh Size (mm)											
	32	38	45	51	57	64	70	76	89	102	114	127
Species												
WPer	1.96	1.71	0.81	1.33	1.37	1.60	1.17	2.02	1.76	1.57	0.91	1.26
YPer	0.75	0.94	0.71	0.34	0.34	0.77	1.12	0.74	0.37	0.73	0.86	
FreD	1.47	2.04	1.20	1.43	1.00	1.00	1.12	1.39	0.55	0.62	0.98	0.89
Alew	2.26	2.28	1.92	1.94	1.07		0.69	0.69		0.86	0.63	0.69
Wall	1.57	1.88	1.83	1.09	1.64	1.62	2.06	1.15	0.53	0.70	0.69	1.19
WSuc					0.73	1.35	1.00	0.79	0.76	0.62	0.68	
RaSm	1.55	1.04	2.04	1.14	1.57	1.29	1.09	1.06	0.91	1.07	0.63	0.69
WBas	1.33	1.64	2.42			0.63	0.69	0.63	0.63	0.69	0.69	
SpSh	1.72											
Trpe	2.33	1.33										
GSha					0.69			1.39	1.15	1.15	1.61	2.00

Table 9. Increase in reliability (Reliability in LOG - Reliability with raw measures) from Table 5 and 7.

	Mesh Size (mm)											
Species	32	38	45	51	57	64	70	76	89	102	114	127
WPer	**0.48**	**0.02**	*-0.17*	-0.04	**0.15**	**0.13**	*-0.16*	**0.33**	**0.31**	**0.20**	**0.14**	**0.19**
YPer	*-0.35*	*-0.39*	**0.11**	**0.10**	*-0.10*	*-0.31*	**0.15**	*-0.08*	**0.06**	-0.03	-0.01	
FreD	**0.00**	**0.00**	**0.00**	**0.25**	**0.02**	**0.03**	*-0.19*	*-0.16*	*-0.18*	*-0.28*	**0.20**	*-0.10*
Alew	*-0.09*	**0.26**	**0.33**	**0.39**	**0.20**		**0.00**	**0.00**		**0.10**	**0.00**	**0.00**
Wall	**0.15**	**0.29**	**0.29**	*-0.27*	*-0.08*	*-0.10*	-0.03	**0.30**	**0.08**	**0.18**	**0.17**	*-0.08*
WSuc					**0.12**	**0.36**	**0.02**	**0.41**	**0.10**	**0.13**	**0.00**	
RaSm	-0.02	*-0.09*	**0.00**	*-0.08*	**0.22**	-0.03	**0.04**	**0.14**	**0.11**	**0.20**	**0.00**	**0.00**
WBas	**0.00**	**0.15**	**0.10**			**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	
SpSh	**0.15**											
Trpe	**0.40**	**0.00**										
GSha					**0.00**			**0.00**	**0.05**	-0.01	**0.00**	-0.04

Increase ≥ 0.00 (67 species-mesh variables/94) means that the LOG transformation kept or reduced the proportion of the measurement component given the variation between units compared to raw counts.

Increase < -0.05 (19 species-mesh variables/94) means that the LOG transformation fails to reduce the proportion of the measurement component given the variation between units compared to raw counts.

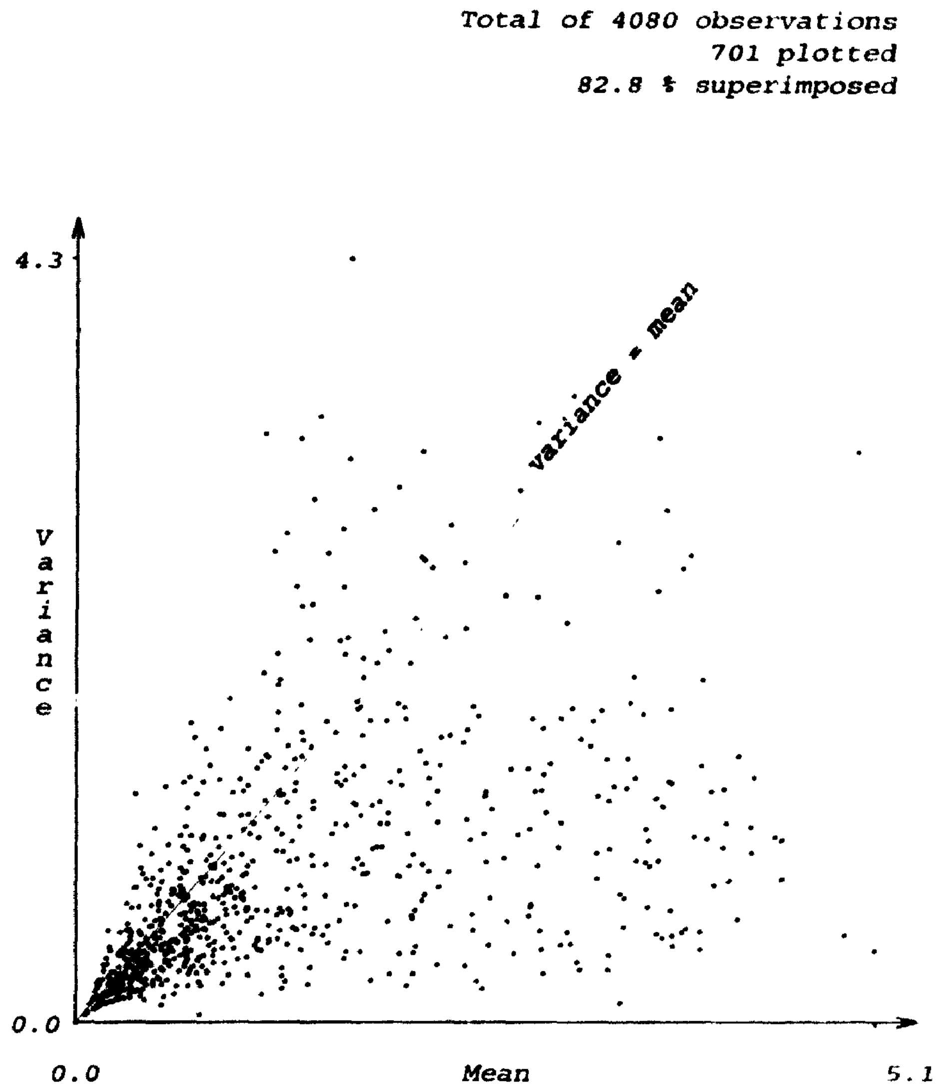
0.13 to 0.77 for the white perch and from -0.20 to 0.86 for the yellow perch.

The ratio of variance to mean is particularly large for the two main species caught by small mesh sizes (Table 6). For white perch of mesh size panels between 38 and 70 mm, the variance-mean ratio is greater than 178/1 but with reliability greater than 0.45 and more often near 0.73 (Table 5). This suggests that even if there is a negative binomial process underlying the measurements, the between units *D* distribution accounts for a large part of these high variance-mean ratios for the species-mesh variables.

The LOG transformation greatly reduced the variance-mean ratios which fall to between 0.34 to 2.42 (Table 8) compared to a range from 0.6 to 287 for the raw counts (Table 6). The reliability tends to increase with the LOG transformation (Tables 5, 7 and especially 9). Where as 20.2 % of the species-mesh variables dropped in reliability more than 5 % and 8.5 % decreased less than 5 %, most cases (71.3 %) had a better or equal reliability with the LOG transformation. Thus, the LOG transformation has the two following benefits: to reduce the variance-mean ratio and to increase or keep, in most cases, the proportion of the true variance in the observed variance.

Figure 6 shows the plot of the sample variance against the sample mean with the LOG transformed counts for the entire data base. The variance-mean ratio decreased greatly, with

Figure 6. Relation between the sample variance and the sample mean of abundance after log transformation Ln(x+1) for all species -separate mesh sizes- and for every year-stratum samples under study.



NB: Scales adjusted for their maximums variances near or less than the actual values of the means, as for the six stations studied. Then, an increase of the expression of the true variance between catch stations measured by the actual variances of LOG counts is expected.

The LOG transformation ($\ln(x+1)$) will be applied to all counts in the data set for consistency.

2.1 Sampling a simple population at many occasions with partial replacement

2.1.1 Notation and sampling procedures

In this subsection I shall define the necessary notation which are used in the subsequent subsections and chapters.

Consider a simple (non stratified) finite statistical population of N units. The subscript j will be used to designate a unit, say U_j, and varies from 1 to the size of the sample or population involved. The subscripts t and t' will be used to designate the occasion when the population (or the unit) is studied and varies from 1 to k occasions. The quantitative character X is a variable that can be observed on all units of the population and may or may not change during the different successive occasions of sampling so that the quantity X_{jt} will be associated with the unit U_j (j=1, 2, ..., N) measured at occasion t.

The following scheme of selection is used to sample the units from the statistical population on successive occasions :

(0) Initial setting of the successive sampling:

At occasion t=1, a sample of size n_t is selected with a simple random sampling design without replacement (later referred as SRSWOR) from the N units of the population. The selected units will be visited and will provide information X_{jt} , j=1, 2, ... n_t.

(1) At the next occasion t' (= t + 1), two selections are made to obtain a current sample of $n_{t'}$ units:

(i) a SRSWOR sample of size $n_{tt'}$, where $n_{tt'} \leq n_t$, is selected from the n_t sampled units available at the previous occasion t. These units will be visited and will provide information $X_{jt'}$, j=1, 2, ..., $n_{tt'}$. This information will be paired with the corresponding information of the same unit at the previous occasion t.

(ii) to complete the sample at occasion t' with a the size of $n_{t'}$ units, a SRSWOR sample of size $(n_{t'}-n_{tt'})$, where $n_{t'} \geq n_{tt'}$, is selected from the $(N-n_t)$ remaining units in the statistical population not sampled at the previous occasion t. These new units will be visited and will provide information $X_{jt'}$, j= $n_{tt'}$+1, $n_{tt'}$+2, ..., $n_{t'}$.

(2) The occasion t' becomes the previous but most recent occasion in the succession and is now referred to as the occasion t. Step (1) is again applied to get the next current sample if needed.

This kind of selection is referred as a sampling design on successive occasions with partial replacement (or partial matching) if strictly $n_{tt'} > 0$ at step (1)(i). In this work, I will cover cases where $n_{tt'}$ may vary from 0 (no paired stations) to the minimum of n_t or $n_{t'}$ (completely paired for at least one occasion). This scheme will be referred later as the partial replacement sampling design or the *PR* sampling design.

Notice that :

(a) With this selection scheme a *visited* unit is discarded from being sampled again for a maximum of one occasion if it has not been randomly selected to stay in the current sample at step (1)(i).

(b) Also, a unit may, by chance, be visited successively for more than two occasions since it can be randomly selected to stay in the current sample at step (1)(i).

Because of (a) and (b), it is possible that two non-consecutive occasions, say t and t', could have $n_{tt'}$ population units in common in their respective samples, and $n_{tt'}$ may be large enough ($n_{tt'} \geq 2$) for some estimations.

2.1.2 Simple population parameters and their estimators

I am interested in the possible change of the average of the quantitative character X that occurs between different sampling occasions of the statistical population.

I will recall some population parameters and estimators related to this interest from Cochran (1977) with the notation of this thesis. First, the true mean of the variable X in the statistical population at any occasion t is given by

$$\mu_{X_t} = \frac{1}{N}\left[\sum_{j=1}^{N} X_{jt}\right] ; \tag{1}$$

and an unbiased estimator of this mean for any occasion t is computed from the n_t units sampled (matched or not with other occasions) by the sampling design at that occasion and is given by

$$\bar{x}_t = \frac{1}{n_t}\left[\sum_{j=1}^{n_t} x_{jt}\right] ; \tag{2}$$

The true variance of the variable X in the statistical population at any occasion t is given by

$$S_{X_t}^{2} = \frac{1}{(N-1)}\left[\sum_{j=1}^{N}(X_{j_t} - \mu_{X_t})^2\right]; \tag{3}$$

and the unbiased estimator of this variance of X at occasion t estimated on the n_t units available at that occasion is given by

$$s_{X_t}^{2} = \frac{1}{(n_t-1)}\left[\sum_{j=1}^{n_t}(X_{j_t} - \bar{x}_t)^2\right]; \tag{4}$$

where the sample mean is given at equation **(2)**.

The true covariance of the variable X between the two occasions t and t' (consecutive or not) in the statistical population is given by

$$S_{X_tX_{t'}} = \frac{1}{(N-1)}\left[\sum_{j=1}^{N}(X_{j_t} - \mu_{X_t})(X_{j_{t'}} - \mu_{X_{t'}})\right]; \tag{5}$$

and the unbiased estimator of this covariance of X between occasion t and occasion t' estimated on the $n_{tt'}$ common units available at both occasions (consecutive or not) is given by

$$s_{X_tX_{t'}} = \frac{1}{(n_{tt'}-1)}\left[\sum_{j=1}^{n_{tt'}}(X_{j_t} - \bar{x}_t^{*})(X_{j_{t'}} - \bar{x}_{t'}^{*})\right]; \tag{6}$$

where the sample means are also estimated on the $n_{tt'}$ common units available at both occasions (consecutive or not), so that, for occasions t and t' ,

$$\overline{x}_t^{*} = \frac{1}{n_{tt'}} \left[\sum_{j=1}^{n_{tt'}} x_{j_t} \right] ; \qquad \overline{x}_{t'}^{*} = \frac{1}{n_{tt'}} \left[\sum_{j=1}^{n_{tt'}} x_{j_{t'}} \right] ; \tag{7}$$

2.1.3 Estimators related to the study of change between two occasions with partial replacement in a simple population

The change of interest could be stated as the difference between the mean at occasion t and the mean at occasion t' (consecutive or not) and its expression would be

$$\Delta_{t't} = \mu_{X_{t'}} - \mu_{X_t} ; \tag{8}$$

I have derived an unbiased estimator of the change $\Delta_{t't}$ under the partial replacement sampling design as described, and its expression is

$$\overline{d}_{t't} = \overline{x}_{t'} - \overline{x}_t ; \tag{9}$$

The sampling variance of the estimator of the change **(9)** is generally expressed as the expectation of the squared deviations of the estimate, from a sample to another, to the true value of the change in the population

$$V(\bar{d}_{t't}) = E(\bar{d}_{t't} - \Delta_{t'tt})^2 ; \qquad \textbf{(10)}$$

Under the partial replacement sampling design, the sampling variance is given by

$$V(\bar{d}_{t't})_{PR} = V(\bar{x}_{t'})_{PR} - 2\,COV(\bar{x}_{t} , \bar{x}_{t'})_{PR} + V(\bar{x}_{t})_{PR} ; \qquad \textbf{(11)}$$

In equation **(11)**, the sampling variance of the mean of X at occasion t is generally expressed as

$$V(\bar{x}_{t}) = E(\bar{x}_{t} - \mu_{X_t})^2 ; \qquad \textbf{(12)}$$

Under the partial replacement sampling design and for any occasion t, this sampling variance is given by

$$V(\bar{x}_{t})_{PR} = \left[\frac{1}{n_t} - \frac{1}{N} \right] S_{X_t}^{2} ; \qquad \textbf{(13)}$$

when $n_t \geq 1$, otherwise 0.

In equation **(11)**, the sampling covariance between the mean X at occasion t and the mean of X at occasion t' is generally expressed as

$$COV(\bar{x}_t, \bar{x}_{t'}) = E(\bar{x}_t - \mu_{x_t})(\bar{x}_{t'} - \mu_{x_{t'}}) \; ; \qquad \textbf{(14)}$$

and I have derived its expression under the partial sampling replacement design for this thesis. The sampling covariance **(14)** is given by

$$\boxed{COV(\bar{x}_t, \bar{x}_{t'})_{PR} = \left[\frac{n_{tt'}}{n_t \, n_{t'}} - \frac{1}{N} \right] S_{x_t \, x_{t'}} \; ;}$$

(15)

when $n_{tt'} \geq 1$, otherwise 0.

An unbiased estimator of the sampling variance of the change **(11)** is given by

$$v(\bar{d}_{t't})_{PR} = v(\bar{x}_{t'})_{PR} - 2\,c(\bar{x}_t, \bar{x}_{t'})_{PR} + v(\bar{x}_t)_{PR} \; ; \qquad \textbf{(16)}$$

where an unbiased estimator of the sampling variance of the mean of X for any occasion t in equation **(16)** is given by

$$v(\, \bar{x}_t \,)_{PR} = \left[\frac{1}{n_t} - \frac{1}{N} \right] s_{X_t}{}^2 \; ; \qquad \textbf{(17)}$$

when $n_t \geq 2$, otherwise 0.

The unbiased estimator of the sampling covariance between occasion t and occasion t' in equation **(16)** is given by

$$\boxed{c\,(\, \bar{x}_t \,,\, \bar{x}_{t'} \,)_{PR} = \left[\frac{n_{tt'}}{n_t \, n_{t'}} - \frac{1}{N} \right] s_{X_t \, X_{t'}} \; ;}$$

(18)

when $n_{tt'} \geq 2$, otherwise 0.

The two key results of equations **(15)** and **(18)**, original from this thesis, were the basis for most subsequent or dependent expressions that were derived in this thesis. These results were derived by the method of building an unbiased estimator given by Lemaire (1985).

2.1.4 Estimators related to the study of change among multiple occasions with partial replacement in a simple population. General case ($k \geq 2$).

When more than two occasions are to be analyzed for change, the appropriate measure of changes can be expressed in terms of variance between occasions.

A measure of this variance would be constructed by the extension of the square of equation **(8)** to more than two cases

$$S^2_{occ} = \frac{1}{k*(k-1)} \left[k\left(\sum_{t=1}^{k} \mu_{x_t}{}^2\right) - \left(\sum_{t=1}^{k}\sum_{t'=1}^{k} \mu_{x_t}\mu_{x_{t'}}\right)\right] ; \qquad \textbf{(19)}$$

This variance between occasions compares each occasion mean to and overall mean which is the average of the occasion means.

An estimator of this expression would be

$$s^2_{occ} = \frac{1}{k*(k-1)} \left[k\left(\sum_{t=1}^{k} \overline{x}_t{}^2\right) - \left(\sum_{t=1}^{k}\sum_{t'=1}^{k} \overline{x}_t\,\overline{x}_{t'}\right)\right] ; \qquad \textbf{(20)}$$

Each occasion mean, estimated with equation **(2)**, has an equal weight in **(20)** even if the sample size differs from an occasion to another.

I have derived the following second order expression of the sampling variance of the measure in equation **(20)**, again by extension of equation **(11)** for the general case $k \geq 2$ occasions

$$V(\,s^2_{occ}\,)_{PR} = \frac{\left[k\left(\sum_{t=1}^{k} V(\,\overline{X}_t)_{PR}\right) - \left(\sum_{t=1}^{k}\sum_{t'=1}^{k} COV(\,\overline{X}_t\,,\overline{X}_{t'})_{PR}\right)\right]}{k*(k-1)} \;; \tag{21}$$

note that when $t = t'$,

$$COV(\,\overline{X}_t\,,\overline{X}_t\,)_{PR} = V(\,\overline{X}_t\,)_{PR} \;; \tag{22}$$

An unbiased estimator of this sampling variance is given by

$$v(\,s^2_{occ}\,)_{PR} = \frac{\left[k\left(\sum_{t=1}^{k} v(\,\overline{x}_t)_{PR}\right) - \left(\sum_{t=1}^{k}\sum_{t'=1}^{k} c(\,\overline{x}_t\,,\overline{x}_{t'})_{PR}\right)\right]}{k*(k-1)} \;; \tag{23}$$

where the estimators of sampling variance and the sampling covariance are defined in equation **(16)** and **(17)**.

Also note that when $t = t'$,

$$c(\,\overline{x}_t\,,\overline{x}_t\,)_{PP} = v(\,\overline{x}_t\,)_{PP} \;; \tag{24}$$

2.2 Stratified statistical population and the *PR* sampling design within each stratum

2.2.1 Notation and sampling procedures

Consider a stratified finite statistical population of units of total size N. The statistical population is subdivided into L non overlapping subsets where a unit is attached, by some criteria, to one and only one subset, called stratum, in all occasions. The subscript h will designate a stratum. Then the j^{th} unit of the stratum h is designate by U_{hj}. In stratum h, there are N_h units and the size of the entire statistical population is given by

$$N = \sum_{h=1}^{L} N_h \; ; \qquad \textbf{(25)}$$

The quantitative character X is a variable that can be observed on all units of the population and may or may not change at different occasions of sampling so that quantity X_{hjt} will be associated with the unit U_{hj} ($j=1, 2, \ldots, N_h$) of stratum h at occasion t.

The PR sampling design will be applied within each stratum independently:

(0) Initial setting of the successive sampling:

At occasion t=1, a SRSWOR sample of size n_{ht} is selected from the N_h units of the stratum h. The units of the sample at t=1 will be visited and will provide information X_{hjt} , j=1, 2, ... n_{ht}.

(1) At the next occasion t' (= t + 1), two selections are made to obtain a current sample of $n_{ht'}$ units:

(i) a SRSWOR sample of size $n_{htt'}$, where $n_{htt'} \leq n_{ht}$, is selected from the n_{ht} sampled units available at the previous occasion t. These units will be visited and will provide information $X_{hjt'}$, j=1, 2, ..., $n_{htt'}$. This information will be paired with the corresponding information of the same unit at the previous occasion t.

(ii) to complete the current sample (occasion t') with a size of $n_{ht'}$ units, a SRSWOR sample of size ($n_{ht'}$-$n_{htt'}$), where $n_{ht'} \geq n_{htt'}$, is selected from the (N_h-n_{ht}) remaining units in the statistical population not sampled at the previous occasion t. These new units will be visited and will provide information $X_{hjt'}$, j= $n_{htt'}$+1, $n_{htt'}$+2, ..., $n_{ht'}$.

(2) The occasion t' becomes the previous but most recent occasion in the succession and is now referred to as the occasion t. Step (1) is again applied to get the next current sample if needed.

This scheme will be referred later as the stratified *PR* sampling design for which a *PR* sampling design is applied independently within each stratum.

2.2.2 Stratified population parameters and their estimators

The overall true mean of the variable X in a stratified statistical population at occasion t is given by

$$\mu_{X_t} = \frac{1}{N}\left[\sum_{h=1}^{L}\sum_{j=1}^{N_h} X_{h_{j_t}}\right]; \tag{26}$$

but it usually expressed (Cochran 1977) as a summation of weighted mean strata as

$$\mu_{X_t} = \sum_{h=1}^{L} W_h\, \mu_{X_{h_t}}; \tag{27}$$

where the true stratum mean is given by

$$\mu_{X_{h_t}} = \frac{1}{N_h}\left[\sum_{j=1}^{N_h} X_{h_{j_t}}\right]; \tag{28}$$

and the stratum weight is given by

$$W_h = N_n \;/\; N\;; \tag{29}$$

Equation **(27)** has an unbiased estimator from the stratified sample at occasion t given by

$$\bar{x}_t = \sum_{h=1}^{L} W_h\, \bar{x}_{h_t}\;; \tag{30}$$

where the stratum mean estimator is given by

$$\bar{x}_{h_t} = \frac{1}{n_{h_t}}\left[\sum_{j=1}^{n_{h_t}} x_{h_{j_t}}\right]; \tag{31}$$

The true variance of the variable X in the statistical population at any occasion t within stratum h, is given by

$$S_{h_{X_t}}^{\;2} = \frac{1}{(\,N_h - 1\,)}\left[\sum_{j=1}^{N_h}(\,X_{h_{j_t}} - \mu_{X_{h_t}}\,)^2\right]; \tag{32}$$

and the unbiased estimator of this variance of X at occasion t, estimated on the n_{ht} units available at that occasion in the stratum h, is given by

$$s_{h_{x_t}}{}^2 = \frac{1}{(n_{h_t} - 1)} \left[\sum_{j=1}^{n_{h_t}} (x_{h_{j_t}} - \bar{x}_{h_t})^2 \right] ; \tag{33}$$

The true covariance of the variable X between the two occasions t and t' (consecutive or not) within the stratum h is given by

$$S_{h_{x_t x_{t'}}} = \frac{1}{(N_h - 1)} \left[\sum_{j=1}^{N_h} (X_{h_{j_t}} - \mu_{h_{x_t}})(X_{h_{j_{t'}}} - \mu_{h_{x_{t'}}}) \right] ; \tag{34}$$

and the unbiased estimator of this covariance of X between occasion t and occasion t' estimated within the stratum h on the $n_{htt'}$ common units available at both occasions (consecutive or not) is given by

$$s_{h_{x_t x_{t'}}} = \frac{1}{(n_{h_{tt'}} - 1)} \left[\sum_{j=1}^{n_{h_{tt'}}} (x_{h_{j_t}} - \bar{x}_{h_t}^{*})(x_{h_{j_{t'}}} - \bar{x}_{h_{t'}}^{*}) \right] ; \tag{35}$$

where the sample mean is estimated only for the $n_{h_{tt'}}$ common units available at both occasions within the stratum h so that, for occasions t and t' within stratum h ,

$$\bar{x}_{h_t}^{*} = \frac{1}{n_{h_{tt'}}}\left[\sum_{j=1}^{n_{h_{tt'}}} x_{h_{tj}}\right] ; \quad \bar{x}_{h_{t'}}^{*} = \frac{1}{n_{h_{tt'}}}\left[\sum_{j=1}^{n_{h_{tt'}}} x_{h_{t'j}}\right] ; \qquad \textbf{(36)}$$

2.2.3 Estimators of the change between two occasions for the stratified *PR* sampling design

In order to study the change between occasions, equations **(26)** and **(30)** replace respectively equations **(1)** and **(2)** in the section of sampling for change with two and with k occasions. The overall unbiased estimator of the change expressed in **(8)** is now given by

$$\bar{d}_{t'/t} = \sum_{h=1}^{L} W_h \, \bar{d}_{h_{t'/t}} \; . \qquad \textbf{(37)}$$

where the unbiased estimator of change in a stratum is given by

$$\bar{d}_{h_{t'/t}} = \bar{x}_{h_{t'}} - \bar{x}_{h_t} \; ; \qquad \textbf{(38)}$$

The sampling variance of the overall estimator of change, under the stratified sampling design where a partial replacement sampling design is applied independently within each stratum, is given by

$$V(\, \bar{d}_{t'/t})_{st_{PR}} = \sum_{h=1}^{L} W_h^2 \; V(\, \bar{d}_{h_{t'/t}} \,)_{h_{PR}} \; ; \qquad \textbf{(39)}$$

and within each stratum

$$V(\bar{d}_{h_{t't}})_{h_{PR}} = V(\bar{x}_{h_{t'}})_{h_{PR}} - 2\, COV(\bar{x}_{h_t}, \bar{x}_{h_{t'}})_{h_{PR}} + V(\bar{x}_{h_t})_{h_{PR}} \;; \qquad \textbf{(40)}$$

In equation **(40)**, the sampling variance of the mean of X under the partial replacement sampling design within stratum h and for any occasion t, is given by

$$V(\bar{x}_{h_t})_{h_{PR}} = \left[\frac{1}{n_{h_t}} - \frac{1}{N_h} \right] S_{h_{x_t}}^2 \;; \qquad \textbf{(41)}$$

when $n_{ht} \geq 1$, otherwise 0.

The sampling covariance between the mean X at occasion t and the mean of X at occasion t' in equation **(40)** has been derived under the partial replacement design within each stratum and it is given by

$$COV(\bar{x}_{h_t}, \bar{x}_{h_{t'}})_{h_{PR}} = \left[\frac{n_{h_{tt'}}}{n_{h_t} n_{h_{t'}}} - \frac{1}{N_h} \right] S_{h_{x_t x_{t'}}} \;; \qquad \textbf{(42)}$$

when $n_{htt'} \geq 1$,otherwise 0.

An unbiased estimator of the sampli g variance of the change (equation **(40)**) is given by

$$v(\bar{d}_{t't})_{st_{PR}} = \sum_{h=1}^{L} W_h^2 \, v(\bar{d}_{h_{t't}})_{h_{PR}} \;; \qquad \textbf{(43)}$$

giving the sampling independence between strata, and

$$v(\, \bar{d}_{h_{t't}})_{h_{PR}} = v(\, \bar{x}_{h_{t'}}\,)_{h_{PR}} - 2\, c(\, \bar{x}_{h_t},\, \bar{x}_{h_{t'}})_{h_{PR}} + v(\, \bar{x}_{h_t}\,)_{h_{PR}}\ ; \qquad \textbf{(44)}$$

where the unbiased estimators of the sampling variance is given by

$$v(\, \bar{x}_{h_t}\,)_{h_{PR}} = \left[\, \frac{1}{n_{h_t}} - \frac{1}{N_h} \,\right] s_{h_{x_t}}{}^2\ ; \qquad \textbf{(45)}$$

when $n_{ht} \geq 2$, otherwise 0.

The unbiased estimator of the sampling covariance, in equation **(43)**, is given by

$$c(\, \bar{x}_{h_t},\ \bar{x}_{h_{t'}}\,)_{h_{PR}} = \left[\, \frac{n_{h_{tt'}}}{n_{h_t} n_{h_{t'}}} - \frac{1}{N_h} \,\right] s_{h_{x_t x_{t'}}}\ ; \qquad \textbf{(46)}$$

when $n_{htt'} \geq 2$, otherwise 0.

The two key results of equations **(42)** and **(46)**, original from this thesis, were the basis for most subsequent or dependent expressions that were derived in this thesis. Again, these results were derived by the method of building an unbiased estimator given by Lemaire (1985).

2.2.4 Estimators of the change between among occasions with a stratified *PR* sampling design - General case ($k \geq 2$)

When more than two occasions are to be analyzed for change, equations **(19)** and **(20)** still hold but with the stratified expressions of equations **(26)** and **(30)**. An expression of the sampling variance of the measure of change in equation **(21)** for the stratified *PR* sampling design is given by

$$V(s_{occ}^{2})_{st_{PR}} = \sum_{h=1}^{L} W_h^{2} \left[\frac{k\left(\sum_{t=1}^{k} V(\bar{x}_{h_t})_{h_{PR}}\right) - \left(\sum_{t=1}^{k}\sum_{t'=1}^{k} COV(\bar{x}_{h_t}, \bar{x}_{h_{t'}})_{h_{PR}}\right)}{k * (k-1)} \right]; \tag{47}$$

Note that when $t = t'$,

$$COV(\bar{x}_{h_t}, \bar{x}_{h_t})_{h_{PR}} = V(\bar{x}_{h_t})_{h_{PR}}; \tag{48}$$

An unbiased estimator of the sampling variance of equation **(47)**, using the definitions in **(45)** and **(46)** is given by

$$v(s_{occ}^{2})_{st_{PR}} = \sum_{h=1}^{L} W_h^{2} \left[\frac{k\left(\sum_{t=1}^{k} v(\bar{x}_{h_t})_{h_{PR}}\right) - \left(\sum_{t=1}^{k}\sum_{t'=1}^{k} c(\bar{x}_{h_t}, \bar{x}_{h_{t'}})_{h_{PR}}\right)}{k*(k-1)} \right] ; \qquad \textbf{(49)}$$

and when $t = t'$,

$$c(\bar{x}_{h_t}, \bar{x}_{h_t})_{h_{PR}} = v(\bar{x}_{h_t})_{h_{PR}} ; \qquad \textbf{(50)}$$

2.3 Estimators of the overall variance and covariance with a stratified *PR* sampling design

Consider now two observable variables X and Y that could be observed on all units of the statistical population.

In order to present an unbiased estimator of the overall covariance between two variables X and Y (or the overall variance when X=Y) that takes into account the stratified and the partial replacement structure, I will first present the unbiased covariance in a stratified design. To do so, I need to define new population parameters and their estimators.

The second order moment about 0 of the product of the two variables X and Y in the population at occasion t is defined by

$$\mu_{X_t Y_t} = \sum_{h=1}^{L} W_h \, \mu_{h_{X_t Y_t}} \; ; \tag{51}$$

where

$$\mu_{h_{X_t Y_t}} = \frac{1}{N_{h_t}} \left[\sum_{j=1}^{N_{h_t}} \left(X_{h_{j_t}} * Y_{h_{j_t}} \right) \right] ; \tag{52}$$

and the unbiased estimator of **(51)** is

$$m_{x_t y_t} = \sum_{h=1}^{L} W_h \, m_{h_{x_t y_t}} ; \qquad \textbf{(53)}$$

where

$$m_{h_{x_t y_t}} = \frac{1}{n_{h_t}} \left[\sum_{j=1}^{n_{h_t}} \left(X_{h_{j_t}} * Y_{h_{j_t}} \right) \right] ; \qquad \textbf{(54)}$$

The sampling covariance of the mean of X_{ht} and the mean of Y_{ht} at occasion t within a given stratum h is given by

$$COV\left(\bar{x}_{h_t} , \bar{y}_{h_t} \right)_h = \left[\frac{1}{n_{h_t}} - \frac{1}{N_h} \right] S_{h_{x_t y_t}} ; \qquad \textbf{(55)}$$

when $n_{ht} \geq 1$, otherwise 0; where

$$S_{h_{x_t y_t}} = \frac{1}{(N_h - 1)} \left[\sum_{j=1}^{N_h} \left(X_{h_{j_t}} - \mu_{h_{x_t}} \right) \left(Y_{h_{j_t}} - \mu_{h_{y_t}} \right) \right] ; \qquad \textbf{(56)}$$

The unbiased estimator of **(55)** is given by

$$c(\,\bar{x}_{h_t},\ \bar{y}_{h_t}\,)_h = \left[\ \frac{1}{n_{h_t}} - \frac{1}{N_h}\ \right] s_{h_{x_t y_t}}\ ; \qquad \textbf{(57)}$$

when $n_{ht} \geq 2$, otherwise 0;

and where

$$s_{h_{x_t y_t}} = \frac{1}{(\,n_{h_t} - 1\,)} \left[\ \sum_{j=1}^{n_{h_t}} (\,x_{h_{j_t}} - \bar{x}_{h_t}\,)(\,y_{h_{j_t}} - \bar{y}_{h_t}\,)\ \right]\ ; \qquad \textbf{(58)}$$

The overall sampling covariance of the stratified mean of X_t (equation **(30)**) and the stratified mean of Y_t (equation **(30)** but with the Y) at occasion t is usually (Cochran 1977) given by

$$COV(\,\bar{x}_t,\ \bar{y}_t\,)_{st} = \sum_{h=1}^{L} W_h^2\ COV(\,\bar{x}_{h_t},\ \bar{y}_{h_t}\,)_h\ ; \qquad \textbf{(59)}$$

and its unbiased estimator is given by

$$c(\,\bar{x}_t,\ \bar{y}_t\,)_{st} = \sum_{h=1}^{L} W_h^2\ c(\,\bar{x}_{h_t},\ \bar{y}_{h_t}\,)_h\ ; \qquad \textbf{(60)}$$

The true overall covariance between X and Y at occasion t in the statistical population is usually given by

$$S_{X_t Y_t} = \frac{1}{(N-1)} \left[\sum_{j=1}^{N} (X_{j_t} - \mu_{X_t})(Y_{j_t} - \mu_{Y_t}) \right] ;$$

and will be presented in an other equivalent form in

$$S_{X_t Y_t} = \frac{N}{(N-1)} [\mu_{X_t Y_t} - \mu_{X_t} \mu_{Y_t}] ; \qquad \textbf{(61)}$$

Its unbiased estimator, in a stratified sampling design, can be presented in equivalent forms as in Gupta *et al.* (1979) or in Lemaire (1985). I will present it in a new format but still equivalent to the two prior works :

$$s_{X_t Y_t} = \frac{N}{(N-1)} [(m_{X_t Y_t} - \overline{x}_t \overline{y}_t) + c (\overline{x}_t , \overline{y}_t)_{st}] ; \qquad \textbf{(62)}$$

where estimators **(52)**, **(30)** and **(59)** are used.

When the partial replacement design is to be considered to achieve the computation of the true overall covariance between X and Y in the statistical population across the k occasions, the occasions become a classification for stratification with equal weights.

Then, the true overall covariance is given by

$$S_{XY} = \frac{N}{(N-1)}[\mu_{XY} - \mu_X \mu_Y] ; \quad \textbf{(63)}$$

where

$$\mu_X = \sum_{t=1}^{k} \left(\frac{1}{k} \right) \mu_{X_t} ; \quad \textbf{(64)}$$

and

$$\mu_{XY} = \sum_{t=1}^{k} \left(\frac{1}{k} \right) \mu_{X_t Y_t} ; \quad \textbf{(65)}$$

Unbiased estimators of **(63)** and **(64)** are given respectively by

$$\bar{x} = \sum_{t=1}^{k} \left(\frac{1}{k} \right) \bar{x}_t ; \quad \textbf{(66)}$$

and

$$m_{XY} = \sum_{t=1}^{k} \left(\frac{1}{k} \right) m_{X_t Y_t} ; \quad \textbf{(67)}$$

The true overall sampling covariance of the two stratified means of *X* and *Y* under a stratified *PR* sampling design is given by

$$COV(\bar{x}, \bar{y})_{st_{PR}} = \sum_{h=1}^{L} W_h^2 \sum_{t=1}^{k} \sum_{t'=1}^{k} \left(\frac{1}{k^2} \right) COV\left(\bar{x}_{h_t}, \bar{y}_{h_{t'}} \right)_{h_{PR}} \; ; \quad (68)$$

where

$$COV\left(\bar{x}_{h_t}, \bar{y}_{h_{t'}} \right)_{h_{PR}} = \left[\frac{n_{h_{tt'}}}{n_{h_t} n_{h_{t'}}} - \frac{1}{N_h} \right] S_{h_{x_t y_{t'}}} \; ; \quad (69)$$

when $n_{htt'} \geq 1$, otherwise 0; and

$$S_{h_{x_t y_{t'}}} = \frac{1}{(N_h - 1)} \left[\sum_{j=1}^{N_h} \left(X_{h_{j_t}} - \mu_{h_{x_t}} \right) \left(X_{h_{j_{t'}}} - \mu_{h_{y_{t'}}} \right) \right] ; \quad (70)$$

Note that when $t = t'$

$$n_{h_{tt'}} = n_{h_t} = n_{h_{t'}} \; ; \quad (71)$$

The unbiased estimator of **(68)** is

$$C(\bar{X}, \bar{Y})_{st_{PR}} = \sum_{h=1}^{L} W_h^2 \sum_{t=1}^{k} \sum_{t'=1}^{k} \left(\frac{1}{k^2} \right) C\left(\bar{x}_{h_t}, \bar{y}_{h_{t'}} \right)_{h_{PR}} ; \qquad \textbf{(72)}$$

where

$$C\left(\bar{x}_{h_t}, \bar{y}_{h_{t'}} \right)_{h_{PR}} = \left[\frac{n_{h_{tt'}}}{n_{h_t} n_{h_{t'}}} - \frac{1}{N_h} \right] s_{h_{X_t Y_{t'}}} ; \qquad \textbf{(73)}$$

when $n_{htt'} \geq 2$, otherwise 0; and where

$$s_{h_{X_t Y_{t'}}} = \frac{1}{(n_{h_{tt'}} - 1)} \left[\sum_{j=1}^{n_{h_{tt'}}} \left(x_{h_{j_t}} - \bar{x}_{h_t}^{*} \right) \left(x_{h_{j_{t'}}} - \bar{y}_{h_{t'}}^{*} \right) \right] ; \qquad \textbf{(74)}$$

where the sample mean of X (or Y) is estimated also on the $n_{htt'}$ common units available at both occasions (consecutive or not) within stratum h, so that, for the two occasions t and t'

$$\bar{x}_{h_t}^{\bullet} = \frac{1}{n_{h_{tt'}}}\left[\sum_{j=1}^{n_{h_{tt'}}} X_{h_{j_t}}\right] ; \qquad \bar{x}_{h_{t'}}^{\bullet} = \frac{1}{n_{h_{tt'}}}\left[\sum_{j=1}^{n_{h_{tt'}}} X_{h_{j_{t'}}}\right] ; \qquad \textbf{(75)}$$

When $t = t'$, equation **(71)** is applied and **(75)** becomes

$$\bar{x}_{h_t}^{\bullet} = \frac{1}{n_{h_t}}\left[\sum_{j=1}^{n_{h_t}} X_{h_{j_t}}\right] ; \qquad \textbf{(76)}$$

The unbiased estimator of the overall covariance, in a stratified sampling design with partial replacement within each stratum is given by

$$\boxed{s_{XY} = \frac{N}{(N-1)}\left[\,(m_{XY} - \bar{x}\bar{y}) + c\,(\bar{x},\ \bar{y})_{st_{PR}}\right] ;}$$

where estimators **(67)**, **(66)** for X and for Y, and **(72)** are used.

Equation **(77)** is totally new and takes into account the replacement structure, if any, and the stratification.

3. Analyses of changes over years

3.1 Inference with the partial replacement sampling design

In order to assess significant statistical changes occuring over years, some equations elaborated in Chapter 2 will be recalled.

The inference procedure will be developed for the simple case of $k = 2$ occasions with no stratification in section 3.2.1. In section 3.2.2, the general case with $k \geq 2$ occasions with no stratification will be developed. Finally, stratification will be considered for the two previous cases in section 3.2.3.

3.1.1 Inference between two occasions

I developed an unbiased estimator of the change $\Delta_{t't}$ under the partial replacement sampling design and its expression was given in equation **(9)** and is recalled here

$$\bar{d}_{t't} = \bar{x}_{t'} - \bar{x}_{t} \ ; \tag{78}$$

Its sampling variance was presented at equation **(11)** and is given by

$$V(\ \bar{d}_{t't}\ )_{PR} = V(\ \bar{x}_{t'}\ )_{PR} - 2\,COV(\ \bar{x}_{t}\ ,\ \bar{x}_{t'})_{PR} + V(\ \bar{x}_{t}\ )_{PR} \ ; \tag{79}$$

with its related equations **(13)** and **(15)**.

From the assumption of normality of the character X, the existence of the true $\Delta_{t't}$ and a positive sampling variance, the application of the central limit theorem leads to the property that the random samples will provide estimates of the change which will be approximately normally distributed

$$\bar{d}_{t't} \sim Normal\left(\ \Delta_{t't}\ ,\ V(\ \bar{d}_{t't}\ )_{PR}\right) \ ; \tag{80}$$

leading to the following Z variate

$$Z = \frac{\bar{d}_{t't} - \Delta_{t't}}{\sqrt{V(\ \bar{d}_{t't}\ )_{PR}}} \sim Normal\,(\,0\,,\,1\,) \ ; \tag{81}$$

This Z statistic is the basis for the statistical decision procedure. The Z statistic is approximately normally distributed and the decision can be made by specifying at a given level of significance (α). The null hypothesis is rejected if the absolute value of Z is larger than the critical value ($Z_{\alpha/2}$ or Z_{α}).

In applied situations, it is uncommon to have the true value of the sampling variance of the change (equation **(79)**) but it can be estimated by equation **(16)** recalled here as

$$v(\bar{d}_{t't})_{PR} = v(\bar{x}_{t'})_{PR} - 2c(\bar{x}_t, \bar{x}_{t'})_{PR} + v(\bar{x}_t)_{PR} ; \qquad \textbf{(82)}$$

with its related equations **(17)** and **(18)**.

The above Z variate becomes a t variate

$$t = \frac{\bar{d}_{t't} - \Delta_{t't}}{\sqrt{v(\bar{d}_{t't})_{PR}}} ; \qquad \textbf{(83)}$$

or

$$t = \frac{\bar{d}_{t't} - \Delta_{t't}}{\sqrt{\left(\frac{1}{n_{t'}} - \frac{1}{N}\right)s_{x_{t'}}^{2} - 2\left(\frac{n_{tt'}}{n_t n_{t'}} - \frac{1}{N}\right)s_{x_t x_{t'}} + \left(\frac{1}{n_t} - \frac{1}{N}\right)s_{x_t}^{2}}} ; \qquad \textbf{(84)}$$

This t variate is approximately normally distributed if the sample sizes involved, n_t , $n_{t'}$ and $n_{tt'}$, are large. When this condition cannot be met, the t variate usually approximated a student t distribution with some specific number of degrees of freedom.

To suggest a way to calculate the number of degrees of freedom of the t variate under a *PR* sampling design, I will recall three well known specific case of equation **(84)**:

Case 1 when $n_{tt'}=0$, two independent samples, no common units between the two occasions but a common variance at both occasions.

Case 2 when $n_{tt'} = n_t = n_{t'}$, two paired samples,

Case 3 when $n_{tt'}=0$, two independent samples, no common units between the two occasions without the restriction of a common variance at both occasions.

<u>Case 1</u> : two independent samples, no common units between the two occasions with the assumption (and then the restriction) of the existence of a common variance at both occasions.

This provides no estimates of the sampling covariance between the two occasions and then **(84)** becomes

$$t = \frac{\bar{d}_{t't} - \Delta_{t't}}{\sqrt{\left(\frac{1}{n_{t'}} - \frac{1}{N}\right) s_{x_{t'}}^{2} + \left(\frac{1}{n_t} - \frac{1}{N}\right) s_{x_t}^{2}}} \; ; \qquad \textbf{(85)}$$

If we ignore the finite population correction term ($1 / N$) in the remaining sampling variances, **(85)** becomes

$$t = \frac{\bar{d}_{t't} - \Delta_{t't}}{\sqrt{\frac{s_{x_{t'}}^{2}}{n_{t'}} + \frac{s_{x_t}^{2}}{n_t}}} \; ; \qquad \textbf{(86)}$$

If we assume the existence of a common variance s^2 estimated by

$$s^2 = \frac{(n_{t'} - 1) \; s_{x_{t'}}^{2} + (n_t - 1) \; s_{x_t}^{2}}{n_{t'} + n_t - 2} \; ; \qquad \textbf{(87)}$$

then equation **(86)** becomes the next equation **(88)** which is the well known t-test expressed here with the notation defined in Chapter 2

$$t = \frac{\bar{d}_{t't} - \Delta_{t't}}{\sqrt{s^2 \left(\frac{1}{n_{t'}} + \frac{1}{n_t} \right)}} \; ; \qquad \textbf{(88)}$$

The t variate in equation **(88)** is known to be distributed, under its restrictions, as a student t distribution with a number of degrees of freedom given by

$$\nu_{t\ test} = n_{t'} + n_t - 2\ ; \qquad \textbf{(89)}$$

<u>Case 2</u> : two paired samples, the same units are measured at both occasions so that $n_{tt'} = n_t = n_{t'}$. Then **(84)** becomes

$$t = \frac{\bar{d}_{t't} - \Delta_{t't}}{\sqrt{\left(\frac{1}{n_{tt'}} - \frac{1}{N}\right) s_{x_{t'}}^{\ 2} - 2\left(\frac{1}{n_{tt'}} - \frac{1}{N}\right) s_{x_t x'_t} + \left(\frac{1}{n_{tt'}} - \frac{1}{N}\right) s_{x_t}^{\ 2}}}\ ; \qquad \textbf{(90)}$$

Again, if we ignore the finite population correction term (1 / N) in the sampling variances and covariances, **(90)** becomes

$$t = \frac{\bar{d}_{t't} - \Delta_{t't}}{\sqrt{\frac{s_{x_{t'}}^{\ 2} - 2\, s_{x_t x'_t} + s_{x_t}^{\ 2}}{n_{tt'}}}}\ ; \qquad \textbf{(91)}$$

which is the well known paired t-test. The ' variate in equation **(91)** is known to be distributed as a student t distribution with a number of degrees of freedom given by

$$\nu_{paired\ t\text{-}test} = n_{tt'} - 1\ ; \qquad \textbf{(92)}$$

Since the t-test for independent samples (case 1) and the paired t-test (case 2) are two specific cases of the general expression **(84)**, the t variate of **(84)** should be distributed as a student t distribution with number of degrees of freedom consistent with these two specific and opposite cases.

I suggest here that a way to compute the appropriate number of degrees of freedom available for **(84)** that satisfies the two extreme cases described would depend on the total number of X observations (say n_{obs}), the number of occasions involved (say k) and the number of units that have been observed more than once (say n_{paired}). Then the computation of the maximum number of degrees of freedom available for **(84)** is given by

$$\nu_{PR_{max}} = (n_{obs}-1) - (k-1) - \begin{bmatrix} (n_{paired}-1) \ \ if \ \ n_{paired} > 1 \\ \\ otherwise \ 0 \end{bmatrix} ; \qquad \textbf{(93)}$$

Appendix 1 applies this way of computing the number of degrees of freedom and uses a simple structure of samples to compare the two specific cases presented before.

The condition that restricted the use of the n_{paired} in equation **(93)** comes from the following observation: to estimate an appropriate average for a given unit, it is necessary to observe this unit more than once in order to obtain a variance within this unit; then to make an appropriate variance between the units it is necessary to have more than one unit that can provide such estimation of its appropriate average. The sampling covariance in equation **(84)** cannot be estimated with less than two paired units.

Case 3 : two independent samples, no common units between the two occasions but in this case a common variance at both occasions cannot be assumed.

This provides no estimates of the sampling covariance between the two occasions and if we ignore the finite population correction term (1 / N) in the remaining sampling variances, **(84)** becomes

$$t = \frac{\bar{d}_{t't} - \Delta_{t't}}{\sqrt{\dfrac{s_{X_{t'}}^{2}}{n_{t'}} + \dfrac{s_{X_t}^{2}}{n_t}}} \; ; \qquad \textbf{(94)}$$

which is the well known Satterthwaite t-test for unequal variances.

Satterthwaite (1946) developed a way to calculate its number of degrees of freedom and it is given by

$$\nu_{Satterthwaite} = \frac{\left(\dfrac{s_{X_{t'}}^{2}}{n_{t'}} + \dfrac{s_{X_{t}}^{2}}{n_{t}}\right)^{2}}{\dfrac{\left(\dfrac{s_{X_{t'}}^{2}}{n_{t'}}\right)^{2}}{(n_{t'}-1)} + \dfrac{\left(\dfrac{s_{X_{t}}^{2}}{n_{t}}\right)^{2}}{(n_{t}-1)}} \; ; \qquad \textbf{(95)}$$

The number of degrees of freedom of this variate is not restricted by the assumption of equal variances at both occasions and the equation **(95)** is found to arrange the numbers of degrees of freedom from the two independent sampling variances (at t and at t') to approximate the Chi-square distribution of the combined sampling variances in the variate. The equation **(95)** has the characteristic of providing a number of degrees of freedom bounded by the number of degrees of freedom of the largest sampling variance when the sampling variances are unequal, and by the sum of the number of degrees of freedom of the two sampling variances involved when the sample sizes and sampling variances are equal.

In a practical sense, when we have a balanced situation where the two sample sizes are equal and the variances at the two occasions are equal, there is no difference between the numbers of degrees of freedom of equation **(89)** and equation **(95)** and no distinction between the t variate expressed at equation **(88)** and equation **(94)**. This leads to the idea that the Satterthwaite case is more general than the t-test for equal variances which is only a specific case of the Satterthwaite case.

Number of degrees of freedom of the *t* variate for a *PR* sampling design

The *t* variate associated with the *PR* sampling design was described in detail at equation **(84)** and is recalled here :

$$t_{PR} = \frac{\bar{d}_{t't} - \Delta_{t't}}{\sqrt{\left(\frac{1}{n_{t'}} - \frac{1}{N}\right) s_{x_{t'}}{}^{2} - 2\left(\frac{n_{tt'}}{n_t n_{t'}} - \frac{1}{N}\right) s_{x_t x'_t} + \left(\frac{1}{n_t} - \frac{1}{N}\right) s_{x_t}{}^{2}}} \; ; \qquad \textbf{(96)}$$

In order to take into account unequal sampling variances as in the Satterthwaite case, I suggest that the maximum number of degrees of freedom indicated in equation **(93)** should be adjusted as it is for independent samples cases 1 and 3, so that, using the two following equations :

$$\nu_{equal} = \left[\sum_{t=1}^{k} n_t\right] - k \; ; \tag{97}$$

$$\nu_{unequal} = \frac{\left(\sum_{t=1}^{k}\left(\frac{1}{n_t} - \frac{1}{N}\right) s_{X_t}{}^{2}\right)^{2}}{\sum_{t=1}^{k} \frac{\left(\left(\frac{1}{n_t} - \frac{1}{N}\right) s_{X_t}{}^{2}\right)^{2}}{(n_t - 1)}} \; ; \tag{98}$$

The number of degrees of freedom for expression (96) would decrease from the maximum as the sampling variances and/or the sample sizes became unequal, so that the number of degrees of freedom would be given by

$$\nu_{PR} = \nu_{PR_{max}} \left(\frac{\nu_{unequal}}{\nu_{equal}} \right) \; ; \tag{99}$$

Equation (99) is suggested here until statisticians work out the approximate probability distribution of a combination of variances and covariance, with a covariance that may have fewer degrees of freedom than their related variances.

3.1.2 Inference in multiple occasions - General case ($k \geq 2$)

When more than two occasions are involved in the statistical analysis of change, the measure of the change has been derived in equation **(20)** as the variance among occasions, and an unbiased estimator of the sampling variance was given at equation **(23)**.

These two estimators now are integrated in a F variate in the next equation

$$F = \frac{s_{occ}^{2}}{V\left(s_{occ}^{2} \right)_{PR}} \; ; \qquad \textbf{(100)}$$

In the k occasions, the total number of X observations, n_{obs}, is given by

$$n_{obs} = \sum_{t=1}^{k} n_t \; ; \qquad \textbf{(101)}$$

and n_{paired} is the number of units during the k occasions that have been observed more than once. Then, using equation **(99)** that refers to equations **(97)**, **(98)** and **(93)** using **(101)**, I suggest that this F variate would be approximately distributed as a Fisher-Snedecor F distribution with (k - 1) degrees of freedom for the numerator and ν_{PR} degrees of freedom (equation **(99)**) for the denominator.

Equation (100) and its numbers of degrees of freedom are consistent with the specific cases associated with more than 2 occasions.

With k occasions, the one-way analysis of variance (that assumes the existence of a common variance at the k occasions) is the specific case when no paired units are found and with equal sample sizes and occasion variances. The two-way analysis of variance with only one replicate per cell where unit and occasion are the factors involved in the analysis of the k by $n_{tt'}$ observations is the specific case when all the units are paired (measured k times). Appendix 2 shows with two numerical examples the analogy between the F variate elaborated at equation (100) and its numbers of degrees of freedom with the one-way and two-way analysis of variance.

The advantages of equation (100) and its numbers of degrees of freedom are that it takes into account the finite population correction factor (1 / N) and does not assume necessarily a common variance.

3.1.3 Inference between two and multiple occasions with the stratified *PR* sampling design

When the stratification is to be considered, equations **(84)** or **(96)** still hold with their stratified estimators. Then the t variate is given by

$$t_{st_{PR}} = \frac{\bar{d}_{t't} - \Delta_{t't}}{\sqrt{\sum_{h=1}^{L} W_h^2 \; v(\bar{d}_{h_{t't}})_{h_{PR}}}} \; ; \qquad \textbf{(102)}$$

which used equation **(37)** for the estimator of change, equation **(8)** for the change $\Delta_{t't}$, and the sampling variance of the change detailed in equation **(43)**.

When more than 2 occasions are involved in the statistical analysis of change, the measure of the change has been derived in equation **(20)**; the variance between occasions is adjusted to estimate the stratified means from equation **(30)**. The unbiased estimator of the sampling variance was given in equation **(49)**.

These two stratified estimators are integrated in an F variate in the next equation

$$F = \frac{s_{occ}^{2}}{v(\, s_{occ}^{2}\,)_{st_{PR}}} \; ; \qquad (103)$$

Then the computation of the maximum number of degrees of freedom available for **(102)** and for **(103)** is given by

$$\nu_{st_{PR_{max}}} = \sum_{h=1}^{L} \nu_{h_{PR_{max}}} \; ; \qquad (104)$$

where the maximum number of degrees of freedom available in a given stratum is given by

$$\nu_{h_{PR_{max}}} = (\, n_{obs_h} - 1\,) - (\, k - 1\,) - \begin{bmatrix} (\, n_{paired_h} - 1\,) \;\; if \;\; n_{paired_h} > 1 \\ \\ otherwise \; 0 \end{bmatrix} \; ; \qquad (105)$$

where the proper definition of $n_{obs\ h}$ and $n_{paired\ h}$ are to be applied within a stratum.

If I define

$$v_{equal_h} = \left[\sum_{t=1}^{k} n_{h_t}\right] - k \; ; \tag{106}$$

then

$$v_{equal_{st}} = \sum_{h=1}^{L} v_{equal_h} \; ; \tag{107}$$

and with

$$v_{unequal_{st}} = \frac{\left[\sum_{h=1}^{L} \sum_{t=1}^{k} W_h^2 \left(\frac{1}{n_{h_t}} - \frac{1}{N_h}\right) s_{x_{h_t}}{}^2\right]^2}{\sum_{h=1}^{L} \sum_{t=1}^{k} \frac{\left[W_h^2 \left(\frac{1}{n_{h_t}} - \frac{1}{N_h}\right) s_{x_{h_t}}{}^2\right]^2}{(n_{h_t}-1)}} \; ; \tag{108}$$

The number of degrees of freedom of expression (102) and for the denominator of expression (103) would decrease from the maximum available as the sampling variances and/or the sample sizes became unequal, so that the number of degrees of freedom would be given by

$$\nu_{st_{PR}} = \nu_{st_{PR_{max}}} \left(\frac{\nu_{unequal_{st}}}{\nu_{equal_{st}}} \right) ; \tag{109}$$

since it is not possible to assume equal sampling variance of all the stratum occasion sampling variances.

The *F* ratio is then used to perform a statistical test on the difference between the occasion means taking into account the units, the stratification and the possible interaction between stratification and occasions.

3.2 Descriptive analyses : Components of Change over years

Jassby *et al.* (1990) addressed the important issue in ecological time series by reducing multivariate sets of data to manageable proportions. In this perspective, the study of all individual variables would necessary overevaluate the number of "significant" differences over time according to level of signification specified.

Jassby *et al.* (1990) suggested a Principal Component Analysis approach to reduce the dimension of problems involving multiple variables. Since all species-mesh variables in the study are LOG transformed counts of fish, consistent between them and in units, two PCA types are available: the PCA using the covariance matrix and the PCA using the correlation matrix.

The basic difference between the two types is in the standardization of the covariance matrix. With the correlation matrix, each covariance component of the matrix is standardized with the product of the standard deviations of the two implied variables in the covariance. Statistical software needs only a specification such as COV or CORR to cause the PCA to be done on the desired matrix.

A PCA on the correlation matrix can be produced if all the original x variables were standardized before doing a PCA on the covariance matrix, i.e.

$$y_j = \frac{x_j}{\sqrt{s_x^2}} \text{ ; for all } j \text{ units}$$

each individual observation of a given variable is standardized by the square root of the overall variance of that variable[1].

The new derived variables from the PCA (COV or CORR) may show statistical difference among years if these observed differences in the original variables are large enough or well correlated between the analysed variables, but it is not guaranteed. Few sets of variables with large or moderate variances may be sufficiently correlated to emerge as major principal components. PCA with the covariance matrix could produce this kind of situation in which the "between years" independent patterns are expressed in the smaller principal components. PCA with the correlation matrix could also produce this kind of situation when sets of variables with small variances may be highly correlated and emerge as major principal components. Monitoring the major trends of change of fish abundancies is not granted with Principal Component Analysis on covariances ou correlations.

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[1] Notice that if only the standardization is shown, the PCA is implicitly always performed on centrered observations.

A Principal Component Analysis of change

In order to promote the emergence of principal components that will show trends of change between years, a standardization is suggested before a PCA on covariance matrix

$$y_j = \frac{x_j}{\sqrt{v\left(s^2_{occ}\right)_{PR}}} \text{ ; for all } j \text{ units}$$

In words, each individual observation of a given variable is standardized by the square root of the sampling variance of the estimator of change (equation **(23)** for a simple population or **(49)** for a stratified population). The procedure will be referred as the PCA on the covariance matrix standardized with the sampling variances or the PCA on COV/SV.

The principle of the procedure is that a variable which shows significant change has a small sampling variance relative to the overall variance. Another variable that does not show significant change has a large sampling variance compared to its overall variance. Then the suggested standardization rescale the variation of the observations with the square root of the sampling variance as the scaler. Variables with significant change will show larger variation than those with no significant change. The PCA on the correlation matrix rescale all the variables to a one unit of variance and the square root of the overall variance is then used as a scaler for correlation. The square root of the sampling variance is used here as a descriptive information and specifically as a scaler for change.

This procedure would reweight the variables in the PCA. The shifts in weights are shown in Tables 10a,10b and 10c for the Western basin and Tables 11a, 11b and 11c for the West-Central basin where basic characteristic of the PCA with COV, COV/SV and CORR are compared.

In these tables, the influential weights of the variables for each type of PCA are given. The weight does not take into account the correlation between the variables but is only based on the importance that a variable has given its diagonal value in the matrix compared to the other diagonal values. This weight is relative to the average weight of all the variables involved in the analysis, so that its is comparable from one type of PCA to another.

From Table 10a, the first five species presented (and the most abundant (Table 4)) have the largest influential weights (>2) in the Western basin. Only the first three species such high influential weights in the West-Central basin (Table 11a). Species-mesh variables with low abundances are likely to have little chance to emerge as principal component in a PCA on covariances.

Table 10.a. Influential unitary weights at the beginning of the PCA analysis of each species-mesh variables in Western Basin for PCA using the Covariance matrix.

Species Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	4.568	4.288	4.466	3.748	3.849	5.620	5.506	6.983	6.920	2.914	1.157	0.606
YPer	7.029	5.446	6.135	4.627	3.446	2.804	2.736	1.130	0.630	0.286	0.098	0.051
FreD	0.261	0.224	0.450	3.567	4.094	5.210	5.131	4.897	3.678	3.242	2.015	1.312
Alew	1.495	2.753	2.490	1.477	0.245	0.035	0.024	0.046	0.030	0.082	0.046	0.024
Wall	0.391	0.414	0.914	2.245	3.022	3.249	3.281	2.196	1.755	2.066	1.141	0.901
WSuc	0.024			0.403	0.614	0.922	1.447	1.819	1.591	1.715	1.273	0.238
RaSm	0.181	0.162	0.067	0.383	0.148	0.239	0.250	0.052	0.024	0.024	0.029	
WBas	0.106	0.288	0.388	0.290	0.577	0.759	1.089	1.095	0.778	0.775	0.177	0.030
SiCh	0.640	0.904	1.065	0.945	0.095							0.024
SpSh	1.433	0.386	0.030				0.024			0.024		
Trpe	0.187	0.024										
GSha					0.052	0.059		0.094	0.340	0.305	0.409	0.275
ChCa			0.024	0.082	0.097	0.058	0.086	0.055	0.124	0.251	0.187	0.068
SBas						0.074	0.138	0.080	0.191	0.185	0.449	0.069
RBas	0.024		0.024	0.024	0.190	0.194	0.051	0.047	0.151	0.024		
Lota									0.012			0.016
NRSu					0.016	0.053		0.024	0.052	0.155	0.069	0.016
LaWh										0.015		
Coho			0.024									
Ston		0.030			0.046	0.024		0.046				
EShi	0.024											
Quil					0.024			0.024				
BBul				0.024		0.039		0.024				
Bowf										0.012		
GoRe									0.024			0.046
TaMa				0.046	0.024		0.024					
YBul				0.046		0.024						
Carp										0.024	0.024	0.030
LaTr										0.029		
LaSt											0.024	0.024
U721												
U802										0.059		
FaDa								0.059				
WC:'a								0.024				
Saug									0.024			
RaTr												
MoSc												
NPik							0.024					

Unitary weight = Diagonal value of the species-mesh variable divided by the average of the diagonal values of the submitted matrix.

Table 10.b. Influential unitary weights at the beginning of the PCA analysis of each species-mesh variables in Western Basin for PCA using the Covariance matrix standardized by the sampling variances.

Species Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	1.114	1.274	1.255	1.168	0.827	0.741	1.147	1.106	1.102	0.904	0.906	0.836
YPer	1.657	1.396	1.700	1.204	1.305	1.093	0.895	1.070	0.896	0.906	0.872	1.069
FreD	0.897	0.906	1.113	1.133	1.146	0.988	0.979	0.986	0.892	1.194	1.000	1.094
Alew	1.352	1.661	1.224	1.715	1.061	1.012	0.830	0.918	0.645	0.908	0.918	0.830
Wall	1.177	0.872	1.226	1.482	2.212	2.451	1.472	1.269	1.076	1.034	1.028	0.914
WSuc	0.830			0.810	0.958	0.905	0.819	0.997	0.987	0.893	0.853	1.076
RaSm	1.112	0.867	0.780	1.064	0.981	0.955	0.895	0.708	0.830	0.830	0.651	
WBas	0.895	0.905	1.162	0.912	1.220	1.291	1.290	1.227	1.434	1.028	0.814	0.645
SiCh	0.794	0.900	0.933	1.009	0.866							0.830
SpSh	0.939	0.887	0.645				0.830			0.830		
Trpe	1.054	0.830										
GSha					0.704	0.830		0.830	0.893	0.986	1.020	1.278
ChCa			0.830	0.818	0.859	1.012	0.885	1.083	0.874	0.963	0.940	1.482
SBas						0.722	0.805	0.930	0.830	0.947	0.925	0.867
RBas	0.830		0.830	0.830	0.783	1.051	1.069	1.164	0.880	0.830		
Lota									1.857			1.288
NRSu					1.288	1.375		0.830	0.704	0.962	0.804	1.288
LaWh										1.468		
Coho			0.830									
Ston		0.645			0.817	0.830		0.817				
EShi	0.830											
Quil					0.830			0.830				
BBul				0.830		0.958		0.830				
Bowf										1.857		
GoRe									0.830			0.918
TaMa				0.817	0.830		0.830					
YBul				0.817		0.830						
Carp										0.830	0.830	0.645
LaTr										0.651		
LaSt											0.830	0.830
U721												
U802										0.830		
FaDa								0.830				
WCra								0.830				
Saug									0.830			
RaTr												
MoSc												
NPik							0.830					

Unitary weight = Diagonal value of the species-mesh variable divided by the average of the diagonal values of the submitted matrix.

Table 10.c. Influential unitary weights at the beginning of the PCA analysis of each species-mesh variables in Western Basin for PCA using the Correlation matrix (Covariance matrix standardized by the variances).

Species Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
YPer	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FreD	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Alew	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Wall	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
WSuc	1.000			1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
RaSm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	
WBas	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SiCh	1.000	1.000	1.000	1.000	1.000							1.000
SpSh	1.000	1.000	1.000				1.000			1.000		
Trpe	1.000	1.000										
GSha					1.000	1.000		1.000	1.000	1.000	1.000	1.000
ChCa			1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SBas						1.000	1.000	1.000	1.000	1.000	1.000	1.000
RBas	1.000		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000		
Lota									1.000			1.000
NRSu					1.000	1.000		1.000	1.000	1.000	1.000	1.000
LaWh										1.000		
Coho			1.000									
Ston		1.000			1.000	1.000		1.000				
EShi	1.000											
Quil					1.000			1.000				
BBul				1.000		1.000		1.000				
Bowf										1.000		
GoRe									1.000			1.000
TaMa				1.000	1.000		1.000					
YBul				1.000		1.000						
Carp										1.000	1.000	1.000
LaTr										1.000		
LaSt											1.000	1.000
U721												
U802										1.000		
FaDa								1.000				
WCra								1.000				
Saug									1.000			
RaTr												
MoSc												
NPik							1.000					

Unitary weight = Diagonal value of the species-mesh variable divided by the average of the diagonal values of the submitted matrix.

Table 11.a. Influential unitary weights at the beginning of the PCA analysis of each species-mesh variables in West-Central Basin for PCA using the Covariance matrix.

Species Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	2.389	2.472	4.195	8.399	8.588	8.048	7.998	7.522	4.315	0.853	0.278	0.299
YPer	6.081	5.833	7.102	7.949	5.766	4.570	3.238	1.490	0.627	0.241	0.105	0.077
FreD	0.048	0.112	0.178	1.279	1.765	2.181	2.787	2.795	2.618	2.275	1.083	0.458
Alew	0.628	0.848	0.702	0.457	0.143	0.156	0.082	0.113	0.059	0.006	0.049	0.032
Wall	0.046	0.010	0.031	0.203	0.320	0.646	0.632	0.883	0.552	0.617	0.664	0.457
WSuc				0.011	0.014	0.051	0.091	0.189	0.269	0.572	0.256	0.161
RaSm	0.691	0.623	0.814	1.291	1.958	1.410	1.015	1.416	0.860	0.505	0.196	0.286
WBas	0.055	0.075	0.140	0.217	0.209	0.343	0.202	0.310	0.159	0.081	0.040	
SiCh				0.006					0.006			
SpSh	0.194	0.011										
Trpe	0.211	0.023										
GSha								0.020		0.031	0.029	0.011
ChCa							0.011	0.020		0.006	0.041	
SBas												
RBas							0.006		0.006			
Lota		0.025		0.030	0.030			0.060	0.104	0.214	0.258	0.254
NRSu									0.006	0.017	0.006	
LaWh								0.050	0.025	0.025	0.072	0.052
Coho			0.006	0.006	0.017							
Ston												
EShi	0.005											
Quil							0.025		0.073			
BBul						0.006			0.018			
Bowf		0.006										
GoRe									0.006			
TaMa												
YBul					0.005							
Carp												
LaTr							0.006				0.030	
LaSt												
U721										0.057		
U802												
FaDa												
WCra							0.006					
Saug												
RaTr								0.006				
MoSc								0.006				
NPik												

Unitary weight = Diagonal value of the species-mesh variable divided by the average of the diagonal values of the submitted matrix.

Table 11.b. Influential unitary weights at the beginning of the PCA analysis of each species-mesh variables in West-Central Basin for PCA using the Covariance matrix standardized by the sampling variances.

Species Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	0.991	0.991	0.866	0.761	0.704	0.849	0.973	1.087	0.809	0.969	0.651	0.466
YPer	0.895	0.715	0.777	0.676	0.542	0.514	0.407	0.365	0.427	0.335	0.359	0.379
FreD	0.945	0.467	0.370	0.852	0.721	0.547	0.743	0.704	0.752	0.691	0.844	0.784
Alew	1.422	1.641	1.427	1.301	1.032	1.432	0.729	2.071	2.484	1.960	0.904	0.711
Wall	0.389	2.564	0.391	0.838	0.452	0.571	0.420	0.529	0.444	0.471	0.517	0.372
WSuc				1.954	1.960	0.932	0.654	1.144	0.859	0.505	1.085	0.491
RaSm	0.340	0.373	0.453	0.496	0.458	0.382	0.413	0.351	0.340	0.401	0.424	0.306
WBas	0.457	0.559	1.521	1.399	0.698	0.905	0.647	0.888	0.587	0.556	0.416	
SiCh				1.960					1.960			
SpSh	2.494	1.954										
Trpe	1.565	2.645										
GSha								2.202		1.960	2.172	2.232
ChCa							2.096	1.954		1.960	0.352	
SBas												
RBas							1.960		1.960			
Lota		0.333		0.274	0.274			0.302	0.350	0.325	0.295	0.334
NRSu									1.960	2.124	1.960	
LaWh								0.327	0.333	0.333	0.401	0.312
Coho			1.960	1.960	2.240							
Ston												
EShi	2.287											
Quil							0.333		0.476			
BBul						1.960			0.476			
Bowf		1.960										
GoRe									1.960			
TaMa												
YBul					2.287							
Carp												
LaTr							1.960				0.274	
LaSt												
U721										0.373		
U802												
FaDa												
WCra							1.960					
Saug												
RaTr								1.960				
MoSc								1.960				
NPik												

Unitary weight = Diagonal value of the species-mesh variable divided by the average of the diagonal values of the submitted matrix.

Table 11.c. Influential unitary weights at the beginning of the PCA analysis of each species-mesh variables in West-Central Basin for PCA using the Correlation matrix (Covariance matrix standardized by the variances).

Species Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
YPer	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FreD	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Alew	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Wall	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
WSuc				1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
RaSm	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
WBas	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	
SiCh				1.000					1.000			
SpSh	1.000	1.000										
Trpe	1.000	1.000										
GSha								1.000		1.000	1.000	1.000
ChCa							1.000	1.000		1.000	1.000	
SBas												
RBas							1.000		1.000			
Lota		1.000		1.000	1.000			1.000	1.000	1.000	1.000	1.000
NRSu									1.000	1.000	1.000	
LaWh								1.000	1.000	1.000	1.000	1.000
Coho			1.000	1.000	1.000							
Ston												
EShi	1.000											
Quil							1.000		1.000			
BBul						1.000			1.000			
Bowf		1.000										
GoRe									1.000			
TaMa												
YBul					1.000							
Carp												
LaTr							1.000				1.000	
LaSt												
U721										1.000		
U802												
FaDa												
WCra							1.000					
Saug												
RaTr								1.000				
MoSc								1.000				
NPik												

Unitary weight = Diagonal value of the species-mesh variable divided by the average of the diagonal values of the submitted matrix.

On the other hand (Tables 10c and 11c), the less abundant species will have equal weight to the main species in a PCA on correlations. The correlations only will determine the principal components, uninfluenced by the size of their variances.

Tables 10b and 11b show the rescaling process given the standardization of the covariance matrix by the sampling variances. It has the principal effect of giving weights sometimes over one for some rare species and sometimes less than one for some abundant species.

The suggested procedure will be applied to the data sets for the two basins, and comparison with the PCA on covariance and correlation matrices will be discussed.

4. Assessment of changes in two basins of Lake Erie

4.1 Species assessment

Two sets of statistical tests were conducted on the relative abundances of fish for the two basins. The first set consists of t-tests (equations **(96)** or **(102)**) conducted between years 1987-1988, years 1988-1989 and years 1989-1990. The tests were performed when two years showed a change in catch. The underlying null hypothesis for the t-tests is no change at all, and the alternative is that a change occurred with a two-tailed evaluation of the significance.

The second set consists of F-tests conducted in order to identify species-mesh variables that experienced change during the fou.-year study. A year with no fish observed in a basin was kept in the analysis with zero mean and zero variance. A zero variance would emphasize the consistency of this estimation if there is no reason why the measurement device failed to catch at a catch station.

This choice has an impact on the F-test expressed in equation **(100)**. The among years estimator of change (equation **(19)**) for simple or stratified population) will be computed with some zero means with a fixed $k = 4$ occasions. Since this estimate is a type of average of the squared mean deviations, it will reflect the change with all the possible variation including the zero means. The numerator degrees of freedom will reflect the number of components that are used to estimate the change. The sampling variance of the estimator of change (equation (23) and (49)) will be computed with zero members which could have a greater impact, but it is still relative. If a single count of one fish would have been observed in a sample with all other values equal to zero, the effect would be almost the same as if there were no catch at all.

Since the methodology is not restricted to typical General Linear Models assumptions such as homoscedasticity, the inclusion the zero variance is less critical. The denominator degrees of freedom will not be affected by the zero variance since large variances only have a great effect on the Satterthwaite computation of the degree of freedom. The underlying null hypothesis for the F-tests is no change and the alternative is that at least two occasion means are different (a change occurred). The evaluation of the significance is one-tailed as usual with Anova F-tests.

The following tables cover the two sets of statistical tests. In Tables 12a, 12b and 12c, the significance of the t-tests are presented for the Western basin, followed by Table 13 which reports the significance of the F-tests for the Western basin. Tables 14a, 14b, 14c and 15 covers the West-Central basin.

Figures 7a to 28b show the fluctuations among years, in relative abundances of species that experienced at least one significant change at $\alpha=0.05$ noted by the F-tests in the two basins (Tables 13 and 15).

These figures are presented in pairs. Since a species can be caught by any of the twelve mesh size panels, a first figure shows a between years perspective of the three dimensional graph of relative abundance by year by mesh size of the panel. A second figure follows with the same information but with a mesh size perspective. The significance of the F-tests is reported from Table 13 and 15 on the appropriate figures.

The first set of Figures (from 7 to 18) covers the Western basin fluctuations and the second set (19 to 28) the West-Central basin. Figure 29 represents a map of the relative abundance of white perch at the selected mesh size 45mm for the discussion.

Table 12a. Results (two-tailed significance) of t-tests between year 1987 and 1988 on all species-mesh variables in the Western basin.

Sp\Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	-	-	-	-	-	-	**	*	-	-	-	-
YPer	-	-	-	-	*	-	-	-	-	-	-	-
FreD	-	-	-	-	-	-	-	-	-	-	-	-
Alew	*	**	-	**	.	-	.	.	.	.	.	.
Wall	*	-	**	**	***	***	***	-	-	-	-	-
WSuc	.			-	*	*	-	*	-	-	-	.
RaSm	.	.	.	.	-	-	.	.	.	.	.	
WBas	-	.	**	-	.	***	.	***	-	-	-	.
SiCh	-	-	-	*	.							.
SpSh	-	.	.				.			.		
Trpe	*	.										
GSha					-	.		.	-	-	-	-
ChCa			.	.	.	-	.	.	.	.	-	.
SBas						.	.	-	.	-	-	.
RBas	.		.	.	.	.	-	.	.	.		
Lota									.			.
NRSu					.	.		.	-	.	.	.
LaWh										.		
Coho			.									
Ston		.			.	.		.				
EShi	.											
Quil					.			.				
BBul				.		.		.				
Bowf										.		
GoRe									.			.
TaMa				.	.		.					
YBul				.		.						
Carp										.	.	.
LaTr										.		
LaSt											.	.
U721												
U802										.		
FaDa								.				
WCra								.				
Saug									.			
RaTr												
MoSc												
NPik							.					

Legend · not computed; - not significant at 0.05;
* significant at 0.05; ** significant at 0.01; *** significant at 0.001;

Table 12b. Results (two-tailed significance) of t-tests between year 1988 and 1989 on all species-mesh variables in the Western basin.

Sp\Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	**	**	***	*	-	-	-	-	-	-	*	-
YPer	***	***	**	-	-	-	-	-	-	-	-	.
FreD	.	-	*	*	*	*	-	-	-	-	-	-
Alew	.	-	-	-	.	.	.	.	.	.	.	.
Wall	.	-	-	***	***	***	***	**	-	-	-	-
WSuc	.			-	-	-	-	-	-	-	-	-
RaSm	.	-	.	.	.	-	.	.	.	.	.	
WBas	.	.	-	-	*	**	**	*	**	*	-	.
SiCh	.	-	-	-	.							.
SpSh	-	.	.				.			.		
Trpe	-	.										
GSha					.	.		.	.	-	-	.
ChCa			.	.	.	.	.	.	.	.	-	.
SBas						-	.	.	-	-	-	.
RBas	.		.	.	.	.	.	-	.	.		
Lota									.			.
NRSu					.	.		.	.	.	.	.
LaWh										.		
Coho			.									
Ston		.			.	.		.				
EShi	.											
Quil					.			.				
BBul				.		.		.				
Bowf										.		
GoRe									.			.
TaMa				.	.		.					
YBul				.		.						
Carp										.	.	.
LaTr										.		
LaSt											.	.
U721												
U802										.		
FaDa								.				
WCra								.				
Saug									.			
RaTr												
MoSc												
NPik							.					

Legend . not computed; - not significant at 0.05;
* significant at 0.05; ** significant at 0.01; *** significant at 0.001;

Table 12c. Results (two-tailed significance) of t-tests between year 1989 and 1990 on all species-mesh variables in the Western basin.

Sp\Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	*	.	.	.	.	.	.	.	*	*	.	.
YPer	**	.	**	***	***	*	.	.	.	.	-	-
FreD	-	.	.	.	.	.	.	.	.	.	.	.
Alew	-	-	-	.	-	-	-	-	-	-	-	-
Wall	-	.	.	*	**	.	*	.	.	.	.	.
WSuc	-			.	*	.	.	.	.	.	.	.
RaSm	.	.	-	-	-	.	.	-	-	-	-	
WBas	-	-	-	.	-	.	.	.	***	.	.	-
SiCh	-	.	.	.	.							-
SpSh	.	-	-				-			-		
Trpe	.	-										
GSha					-	-		-	-	.	.	-
ChCa			-	-	-	-	-	-	.	.	.	-
SBas						.	.	-	.	.	.	-
RBas	-		-	-	.	.	-	-	.	-		
Lota									-			-
NRSu					-	-		-	-	-	.	-
LaWh										-		
Coho			-									
Ston		-			-	-		-				
EShi	-											
Quil					-			-				
BBul				-		-		-				
Bowf										-		
GoRe									-			-
TaMa				.	-		-					
YBul				-		-						
Carp										-	-	-
LaTr										-		
LaSt											-	-
U721												
U802										-		
FaDa								-				
WCra								-				
Saug									-			
RaTr												
MoSc												
NPik							-					

Legend · not computed; - not significant at 0.05;
* significant at 0.05; ** significant at 0.01; *** significant at 0.001;

Table 13. Results (two-tailed significance) of F-tests between all years on all species-mesh variables in the Western basin.

Sp\Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	***	***	***	***	-	-	***	***	***	-	-	-
YPer	***	***	***	***	***	-	-	-	*	-	-	-
FreD	-	-	-	***	**	*	*	*	-	-	-	-
AleW	***	***	*	***	*	-	-	-	-	-	-	-
Wall	*	-	***	***	***	***	***	*	-	-	-	-
WSuc	-			-	*	-	-	*	-	-	-	-
RaSm	-	-	-	*	-	-	-	-	-	-	-	
WBas	*	*	**	-	**	***	***	**	***	*	-	-
SiCh	-	-	-	*	-							-
SpSh	*	-	-				-			-		
Trpe	*	-										
GSha					-	-		-	-	-	-	-
ChCa			-	-	-	-	-	*	-	-	-	-
SBas						-	-	-	-	-	-	-
RBas	-		-	-	-	-	-	-	-	-		
Lota									-			-
NRSu					-	-		-	-	-	-	-
LaWh										-		
Coho			-									
Ston		-			-	-		-				
EShi	-											
Quil					-			-				
BBul				-		-		-				
Bowf										-		
GoRe									-			-
TaMa				-	-		-					
YBul				-		-						
Carp										-	-	-
LaTr										-		
LaSt											-	-
U721												
U802										-		
FaDa								-				
WCra								-				
Saug									-			
RaTr												
MoSc												
NPik							-					

Legend · not comp[illegible]ed; - not significant at 0.05;
* significant at 0.05; ** significant at 0.01; *** significant at 0.001;

Table 14a. Results (two-tailed significance) of t-tests between year 1987 and 1988 on all species-mesh variables in the West-Central basin.

Sp\Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	-	-	**	**	***	***	***	***	*	*	-	-
YPer	-	-	-	-	-	*	**	-	-	-	·	-
FreD	·	-	-	-	-	-	-	-	-	-	-	-
Alew	-	-	*	-	·	·	·	·	·	·	·	·
Wall	-	·	·	-	·	*	**	**	**	**	**	·
WSuc				-	·	-	-	-	-	-	-	-
RaSm	-	-	**	-	-	-	-	-	-	-	-	-
WBas	·	·	-	-	*	*	-	*	-	·	·	
SiCh				·					·			
SpSh	-	-										
Trpe	-	-										
GSha								·		·	·	·
ChCa							·	·		·	·	
SBas												
RBas							·		·			
Lota		·		·	·			·	·	-	-	-
NRSu									·	-	·	
LaWh								·	·	·	·	·
Coho			·	·	·							
Ston												
EShi	·											
Quil							·		·			
BBul						·			·			
Bowf		·										
GoRe									·			
TaMa												
YBul					·							
Carp												
LaTr							·				·	
LaSt												
U721										·		
U802												
FaDa												
WCra							·					
Saug												
RaTr								·				
MoSc								·				
NPik												

Legend · not computed; - not significant at 0.05;
* significant at 0.05; ** significant at 0.01; *** significant at 0.001;

Table 14b. Results (two-tailed significance) of t-tests between year 1988 and 1989 on all species-mesh variables in the West-Central basin.

Sp\Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	**	***	***	***	***	***	***	-	-	*	-	-
YPer	***	***	***	***	**	***	-	-	-	-	·	·
FreD	·	-	-	-	-	-	-	-	-	*	-	-
Alew	-	·	·	·	·	·	·	·	·	·	·	·
Wall	-	·	·	·	-	**	**	**	**	**	**	-
WSuc				·	·	-	·	-	-	-	-	-
RaSm	*	·	**	·	**	*	·	**	·	·	·	·
WBas	·	·	·	·	-	*	-	-	-	·	·	
SiCh				·					·			
SpSh	·	·										
Trpe	*	·										
GSha								·		·	·	·
ChCa							·	·		·	·	
SBas												
RBas							·		·			
Lota		·		·	·			·	·	·	-	-
NRSu									·	·	·	
LaWh								·	·	·	-	·
Coho			·	·	·							
Ston												
EShi	·											
Quil							·		·			
BBul						·			·			
Bowf		·										
GoRe									·			
TaMa												
YBul					·							
Carp												
LaTr							·				·	
LaSt												
U721										·		
U802												
FaDa												
WCra							·					
Saug												
RaTr								·				
MoSc								·				
NPik												

Legend · not computed; - not significant at 0.05;
* significant at 0.05; ** significant at 0.01; *** significant at 0.001;

Table 14c. Results (two-tailed significance) of t-tests between year 1989 and 1990 on all species-mesh variables in the West-Central basin.

Sp\Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	-	-	-	-	*	***	***	***	**	-	-	-
YPer	-	-	*	**	**	-	-	-	-	-	·	·
FreD	-	-	-	-	-	-	-	-	-	-	-	-
Alew	·	·	·	·	·	·	·	·	·	·	·	·
Wall	·	·	·	·	·	-	-	-	-	**	*	-
WSuc				·	·	·	·	-	-	-	-	-
RaSm	-	·	*	·	-	-	·	-	·	·	·	·
WBas	·	·	·	·	·	·	-	-	-	-	-	
SiCh				·					·			
SpSh	·	·										
Trpe	-	·										
GSha								·		·	·	·
ChCa							·	·		·	-	
SBas												
RBas							·		·			
Lota		·		·	·			·	·	·	-	-
NRSu									·	·	·	
LaWh								·	·	·	-	·
Coho			·	·	·							
Ston												
EShi	·											
Quil							·		·			
BBul						·			·			
Bowf		·										
GoRe									·			
TaMa												
YBul					·							
Carp												
LaTr							·				·	
LaSt												
U721										·		
U802												
FaDa												
WCra							·					
Saug												
RaTr								·				
MoSc								·				
NPik												

Legend · not computed; - not significant at 0.05;
* significant at 0.05; ** significant at 0.01; *** significant at 0.001;

Table 15. Results (two-tailed significance) of F-tests between all years on all species-mesh variables in the West-Central basin.

Sp\Mesh	32	38	45	51	57	64	70	76	89	102	114	127 (mm)
WPer	**	**	***	***	***	***	***	***	***	-	-	-
YPer	***	***	***	***	***	***	*	-	-	-	-	-
FreD	-	-	-	**	-	-	-	-	-	-	-	-
Alew	*	*	*	*	-	-	-	-	*	-	-	-
Wall	-	-	-	*	*	**	***	***	***	***	***	-
WSuc				-	-	-	-	-	-	-	-	-
RaSm	-	*	**	**	**	**	**	*	*	*	-	-
WBas	-	-	-	-	*	**	-	-	-	-	-	
SiCh				-					-			
SpSh	*	-										
Trpe	-	*										
GSha								-		-	-	-
ChCa							-	-		-	-	
SBas												
RBas							-		-			
Lota		-		-	-			-	*	-	-	-
NRSu									-	-	-	
LaWh								-	-	-	-	-
Coho			-	-	-							
Ston												
EShi	-											
Quil							-		-			
BBul						-			-			
Bowf		-										
GoRe									-			
TaMa												
YBul					-							
Carp												
LaTr							-				-	
LaSt												
U721										-		
U802												
FaDa												
WCra							-					
Saug												
RaTr								-				
MoSc								-				
NPik												

Legend · not computed; - not significant at 0.05;
* significant at 0.05; ** significant at 0.01; *** significant at 0.001;

Figure 7a. Annual relative abundances in the Western basin of white perch by mesh size. Between years perspective.

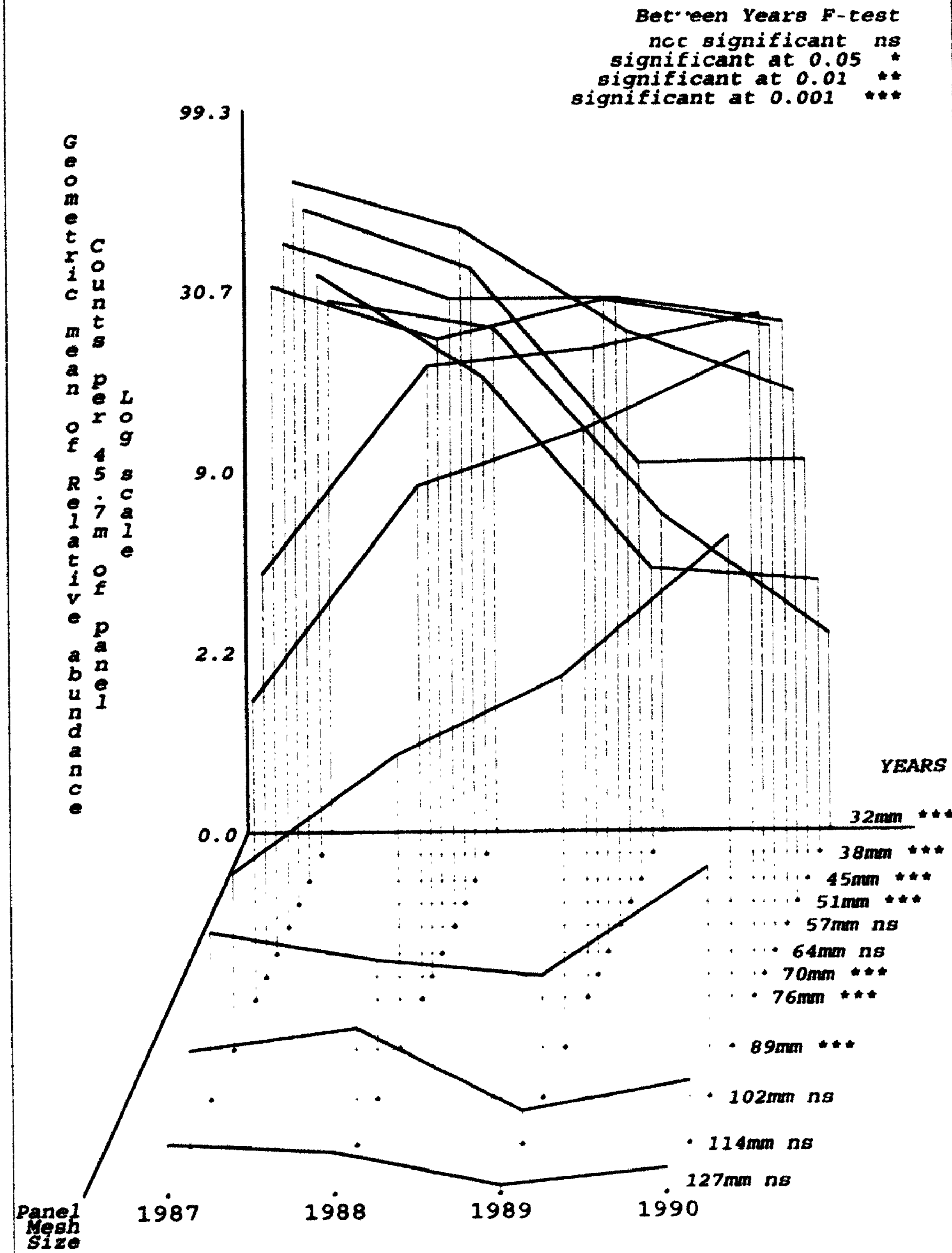


Figure 7b. Annual relative abundances in the Western basin of white perch by mesh size. Between mesh sizes perspective.

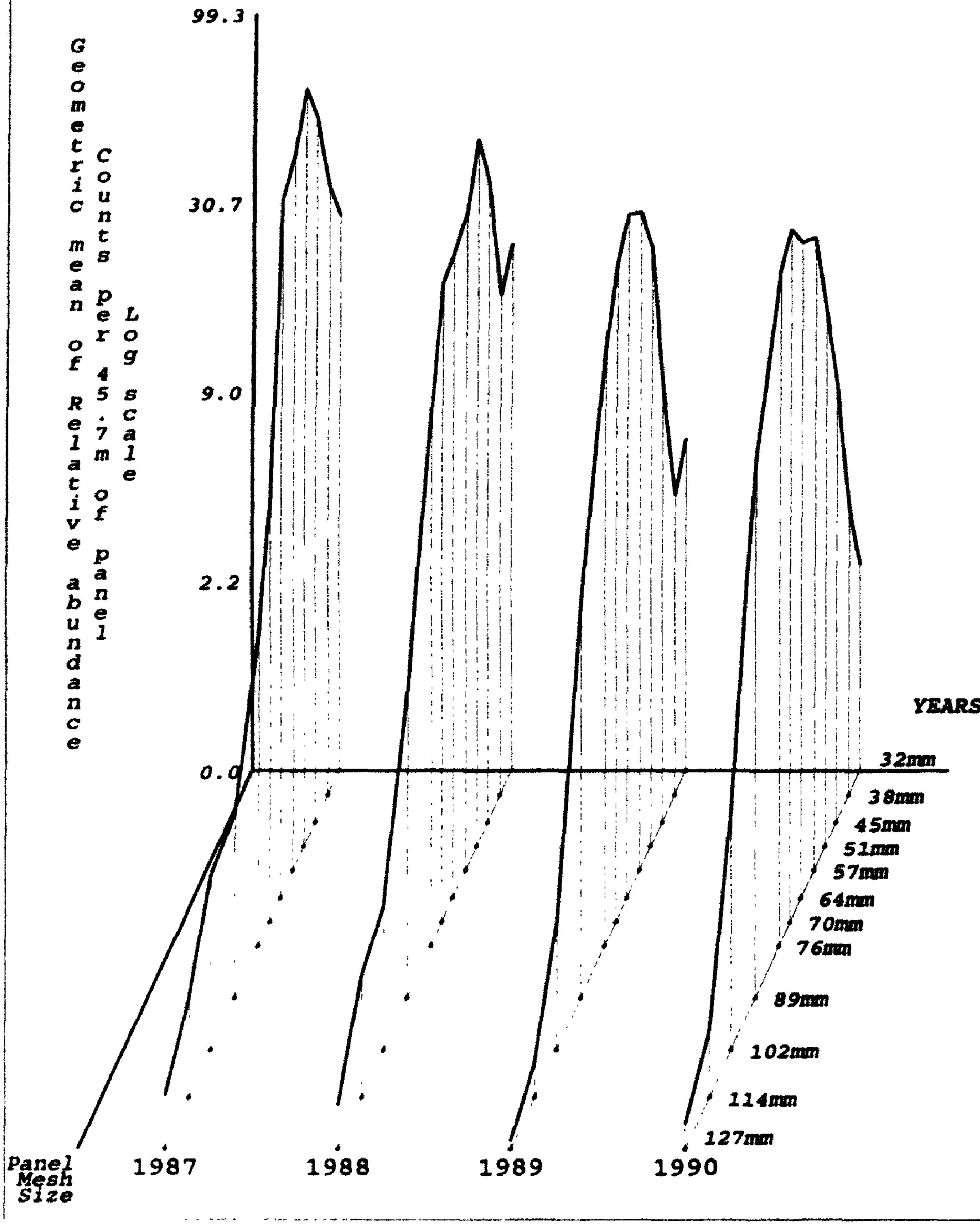


Figure 8a. Annual relative abundances in the Western basin of yellow perch by mesh size. Between years perspective.

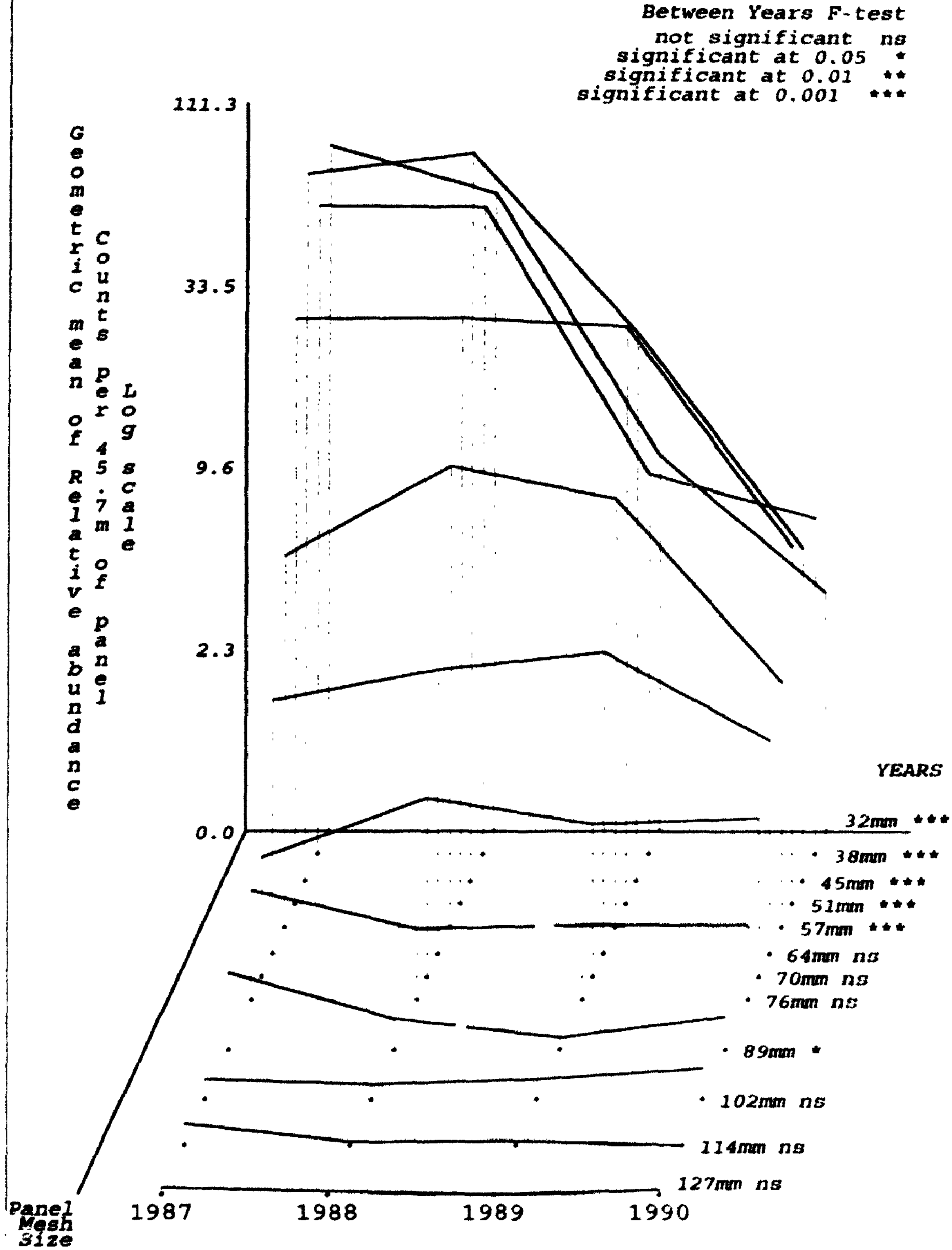


Figure 8b. Annual relative abundances in the Western basin of yellow perch by mesh size. Between mesh sizes perspective.

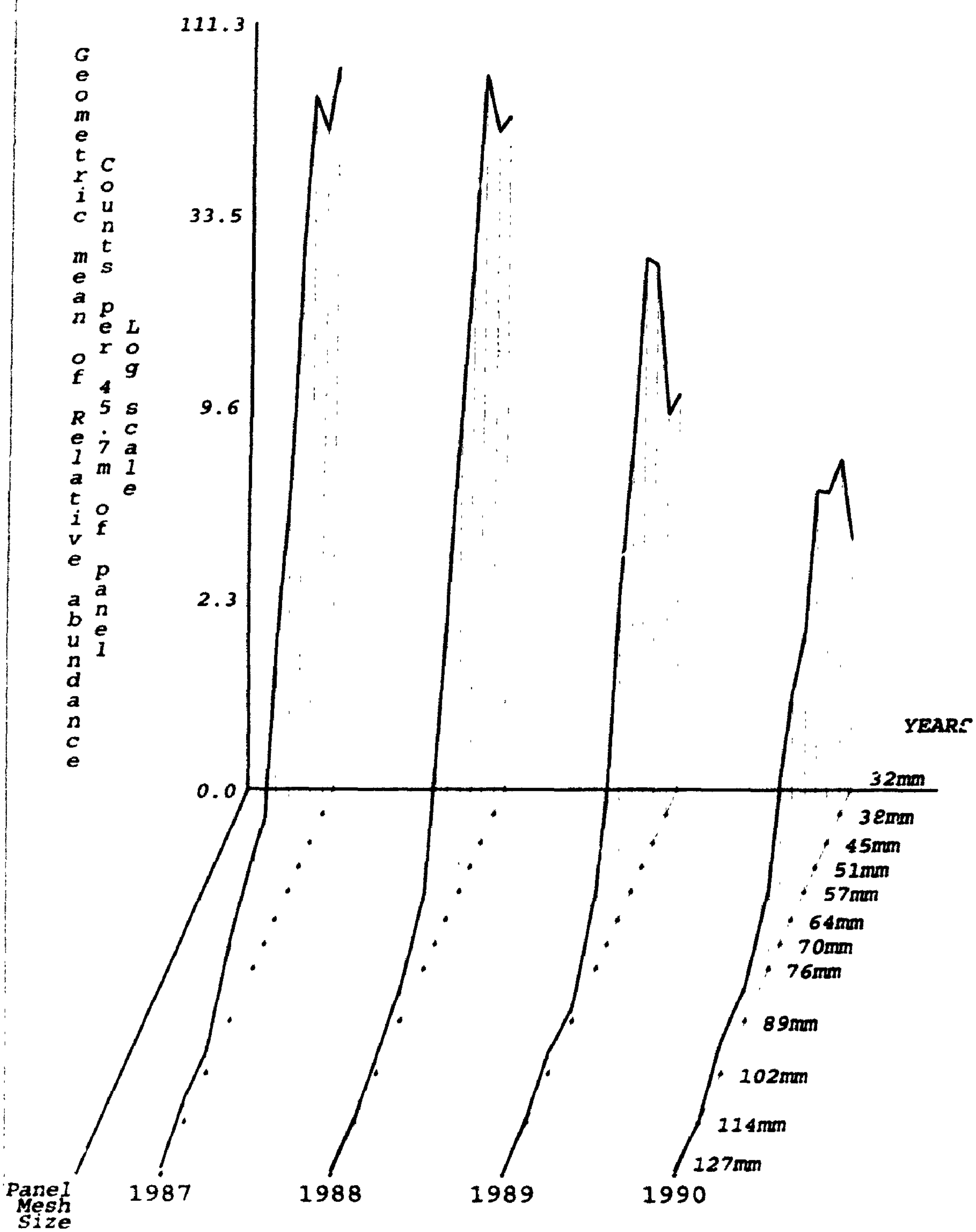


Figure 9a. Annual relative abundances in Western basin of freshwater drum by mesh size. Between years perspective.

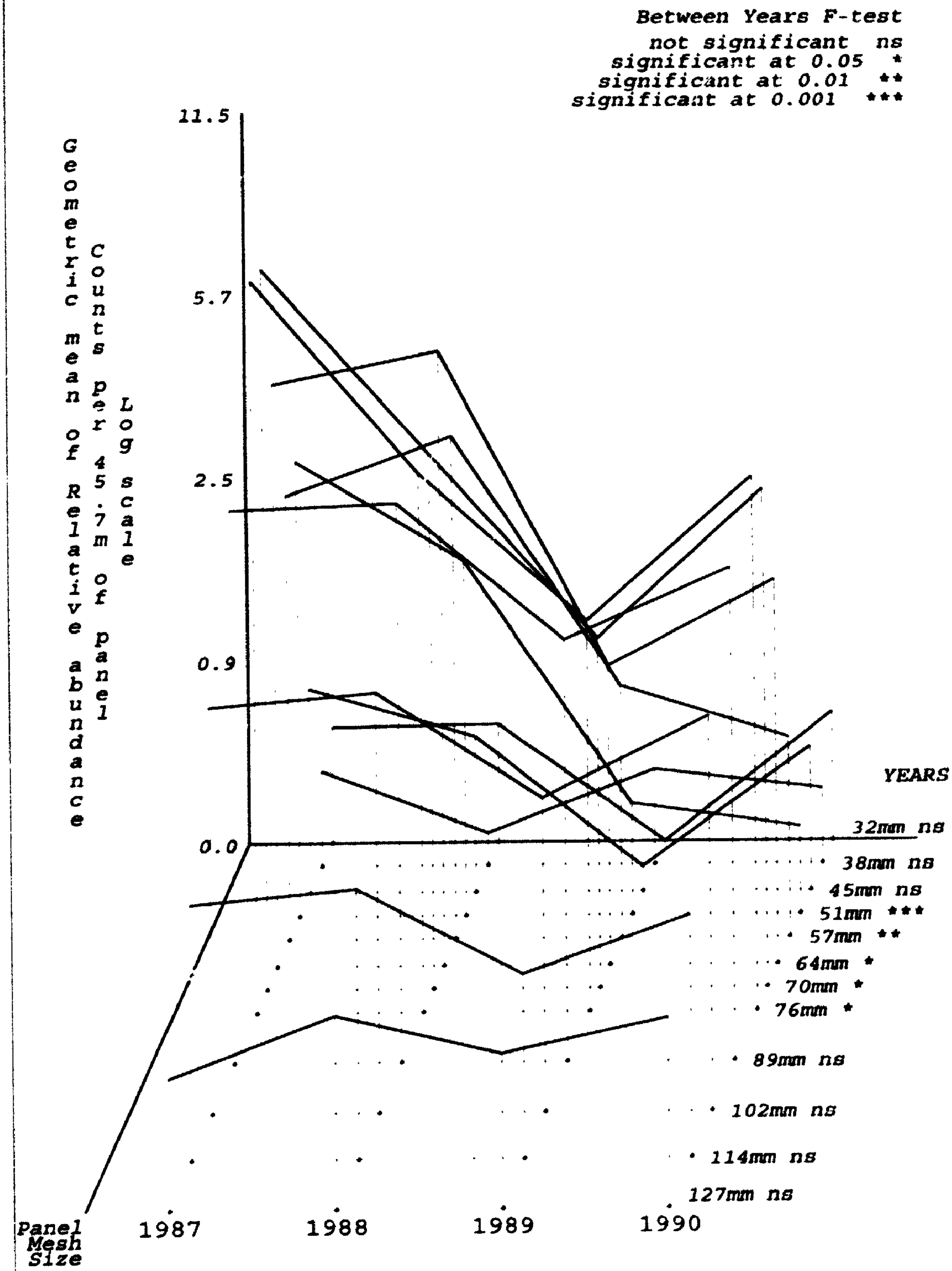


Figure 9b. Annual relative abundances in Western basin of freshwater drum by mesh size. Between mesh sizes perspective.

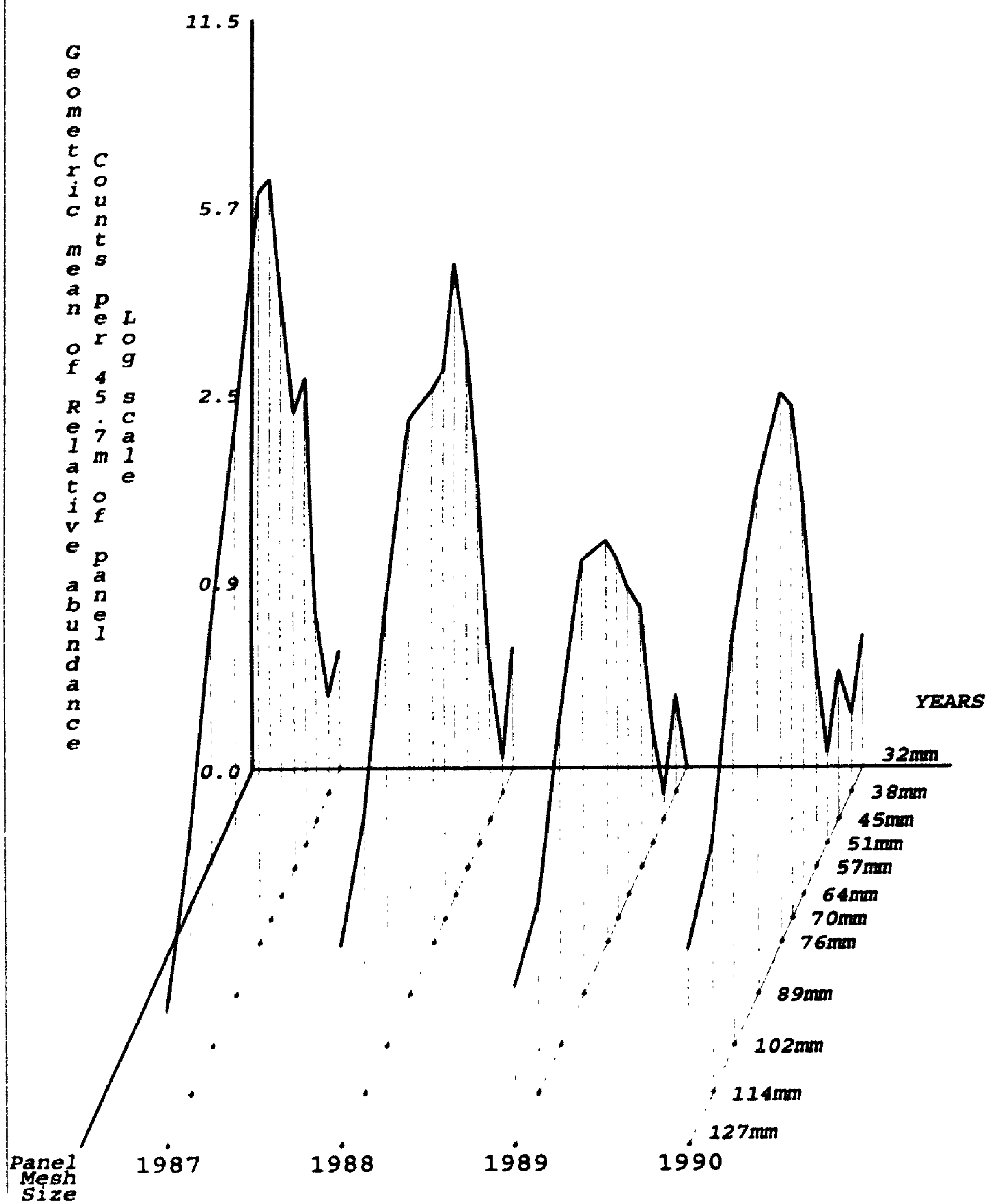


Figure 10a. Annual relative abundances in the Western basin of alewife by mesh size. Between years perspective.

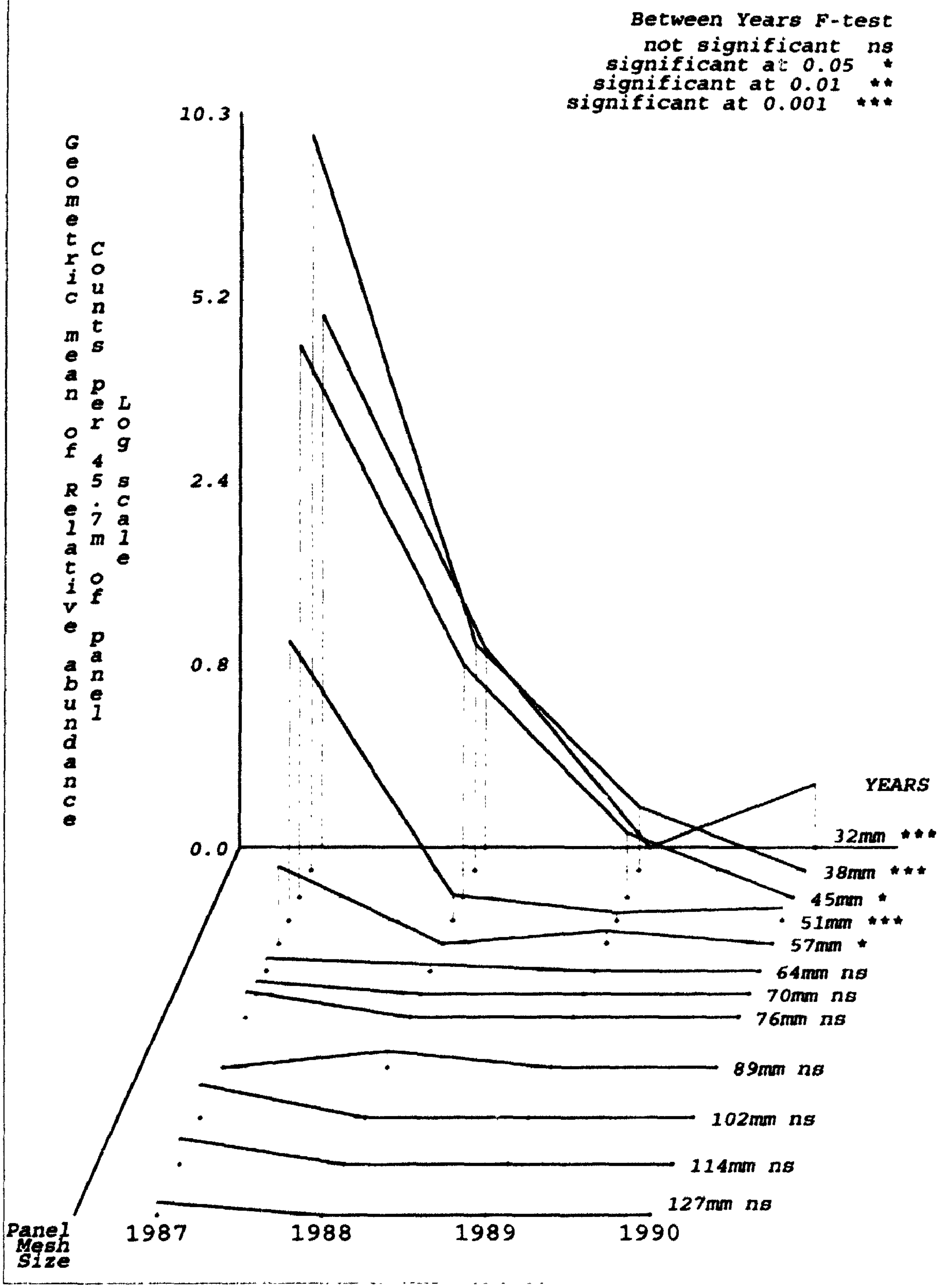


Figure 10b. Annual relative abundances in the Western basin of alewife by mesh size. Between mesh sizes perspective.

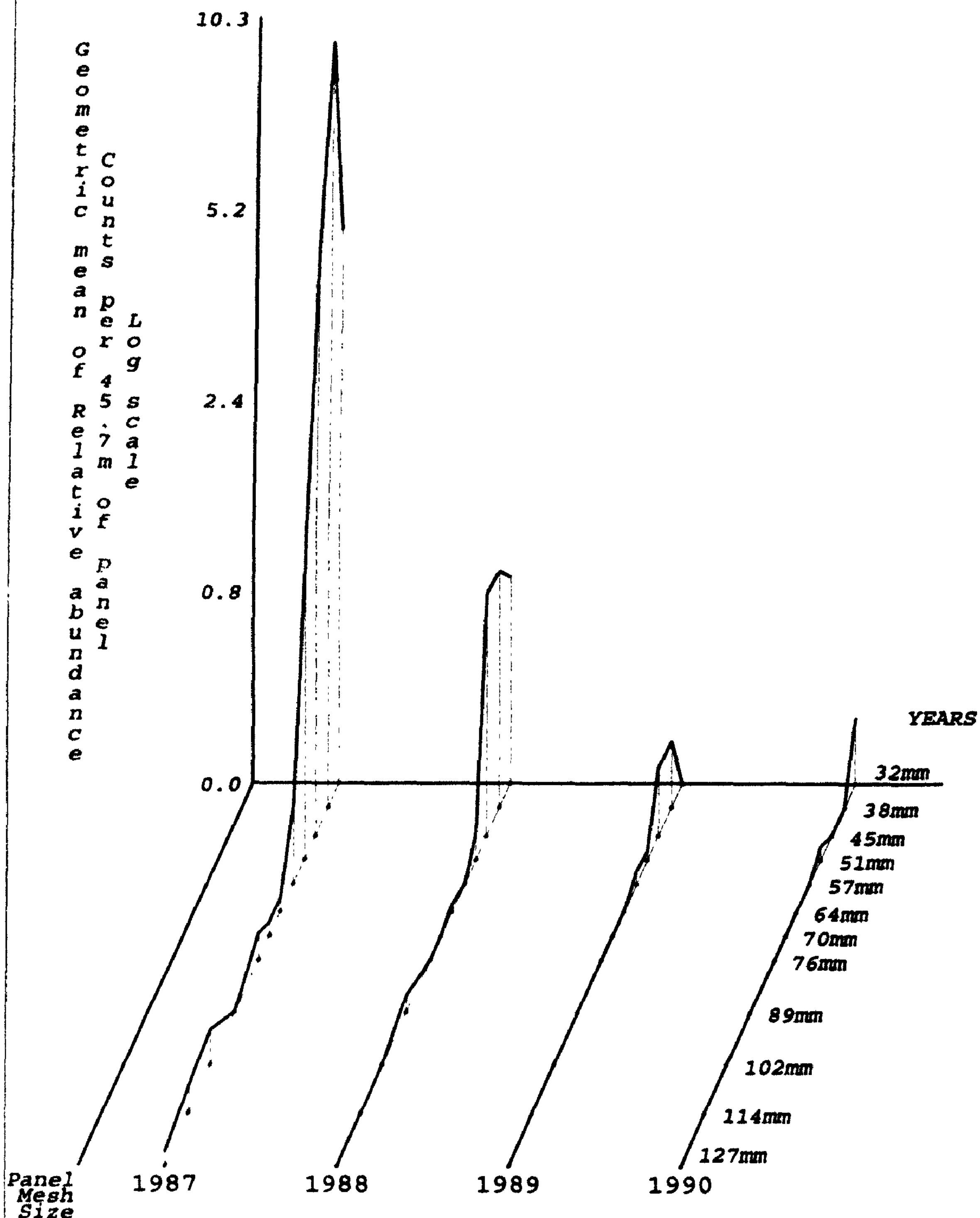


Figure 11a. Annual relative abundances in the Western basin of walleye by mesh size. Between years perspective.

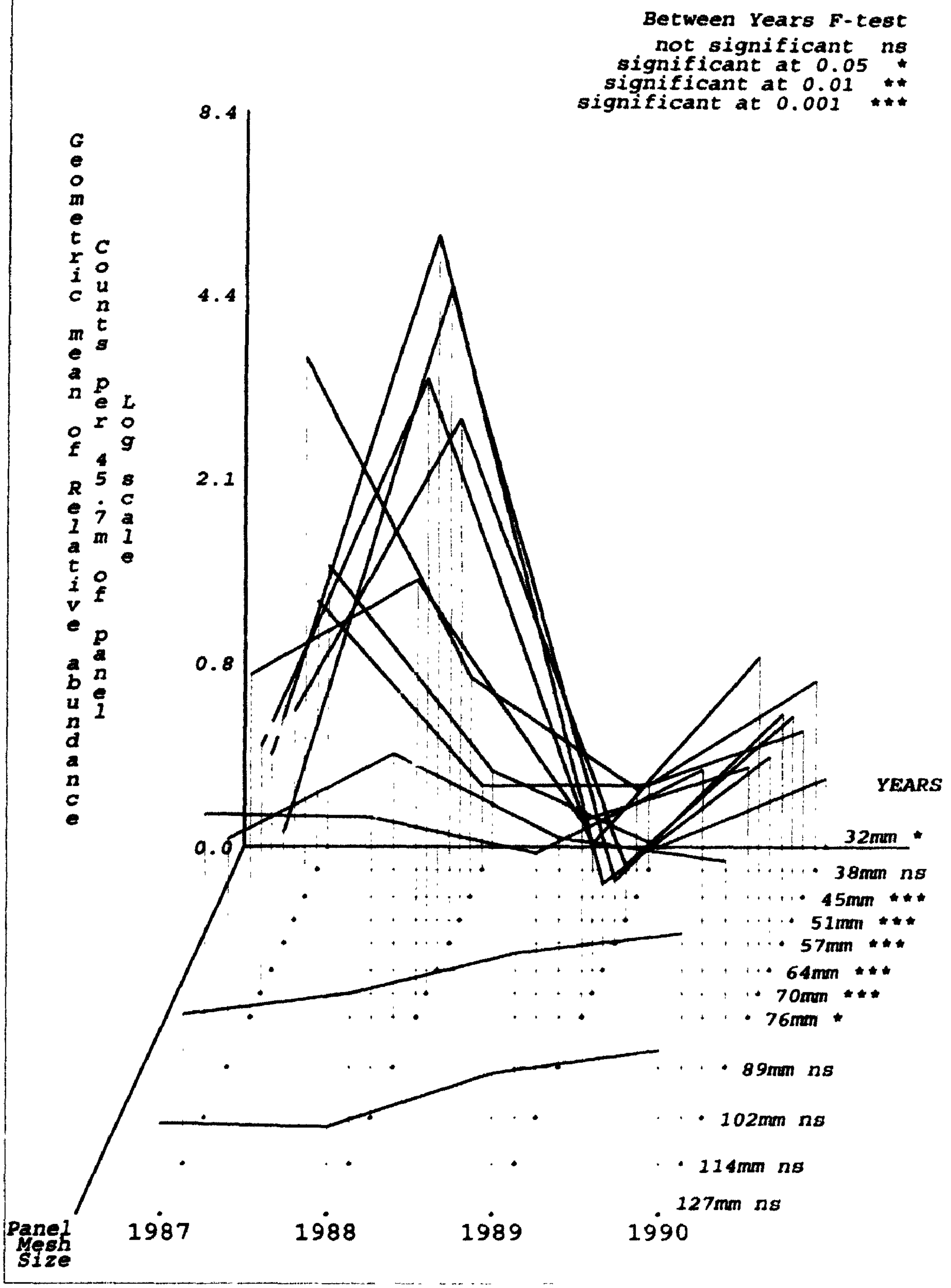


Figure 11b. Annual relative abundances in the Western basin of walleye by mesh size. Between mesh sizes perspective.

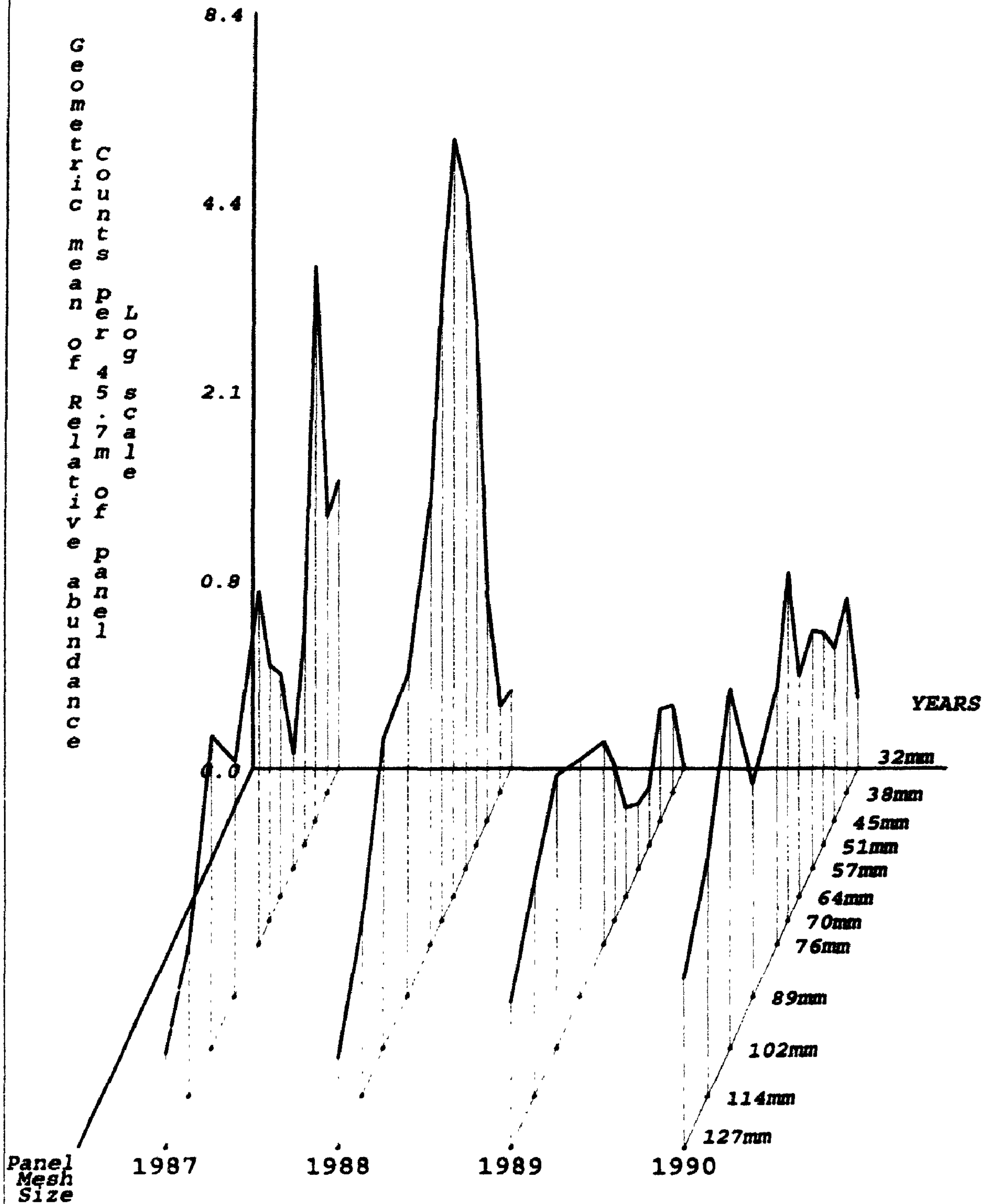


Figure 12a. Annual relative abundances in the Western basin of white sucker by mesh size. Between years perspective.

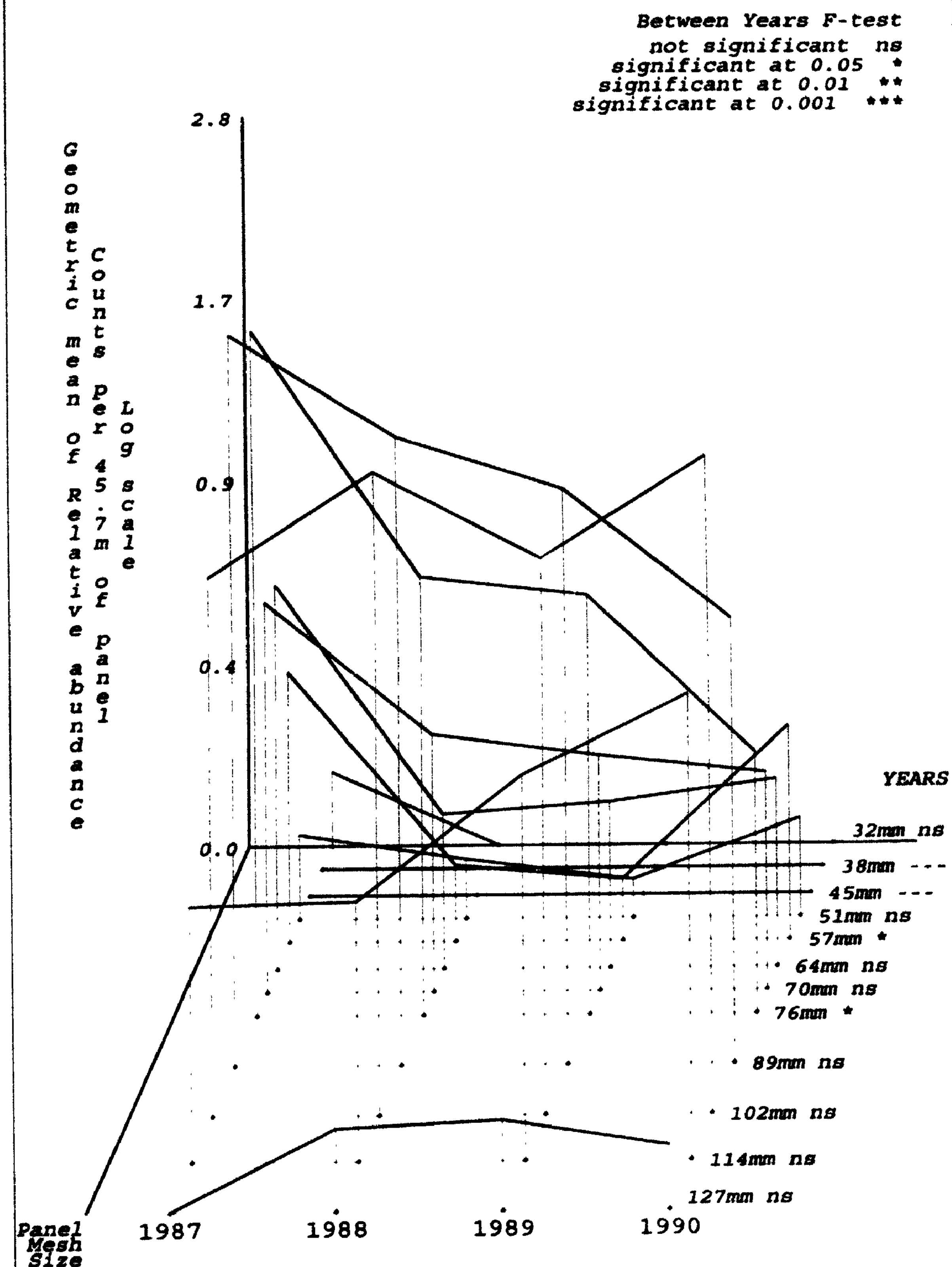


Figure 12b. Annual relative abundances in the Western basin of white sucker by mesh size. Between mesh sizes perspective.

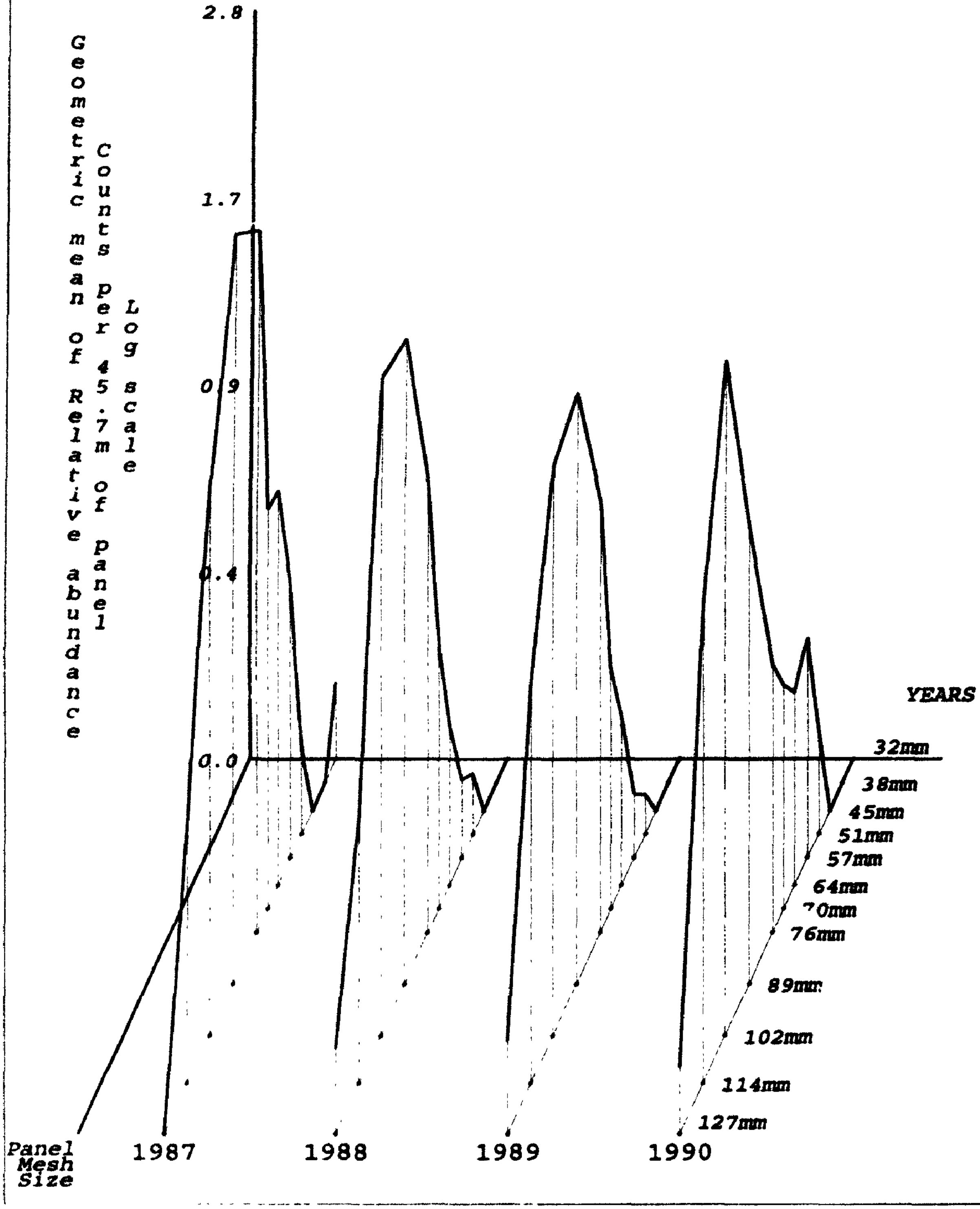


Figure 13a. Annual relative abundances in the Western basin of rainbow smelt by mesh size. Between years perspective.

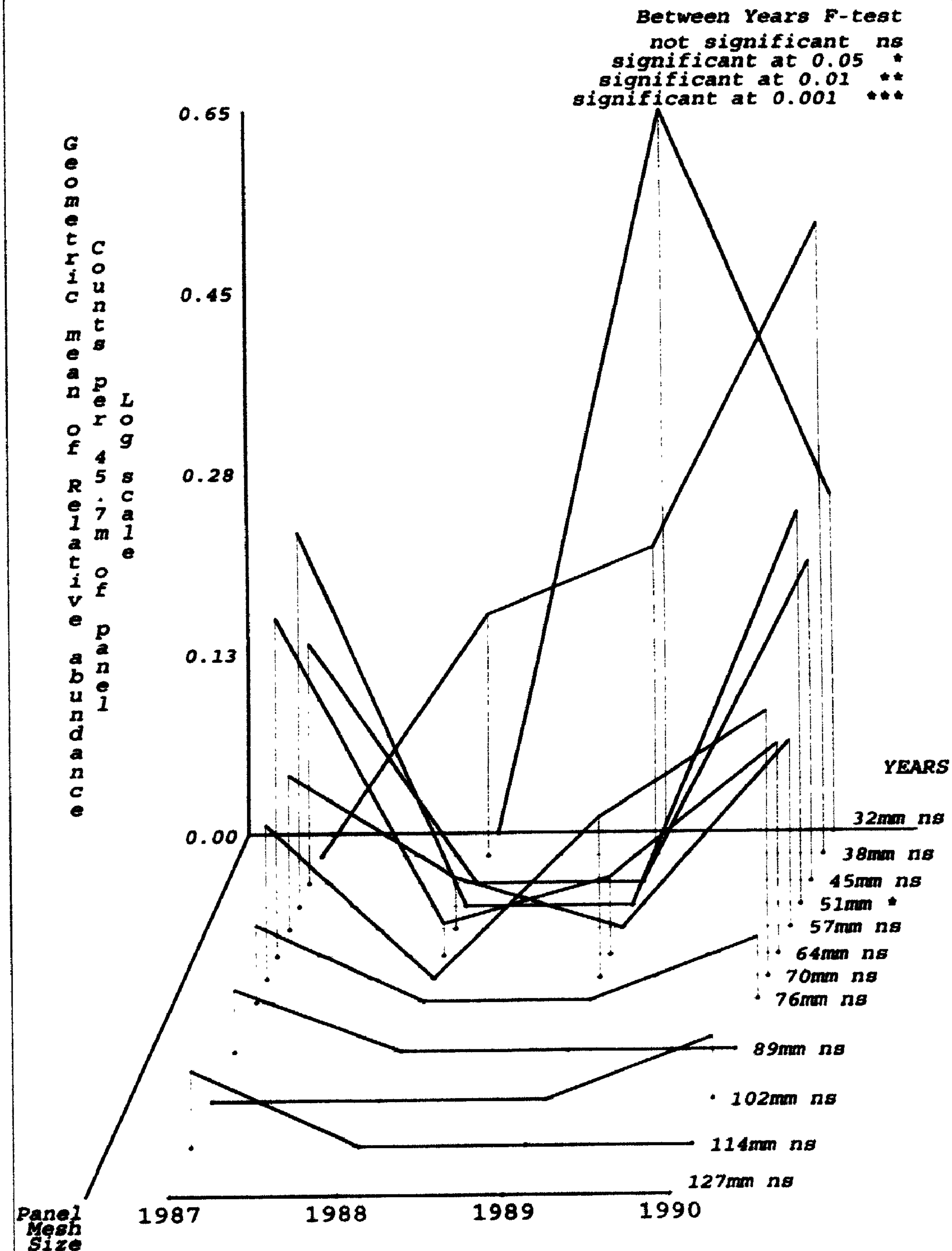


Figure 13b. Annual relative abundances in the Western basin of rainbow smelt by mesh size. Between mesh sizes perspective.

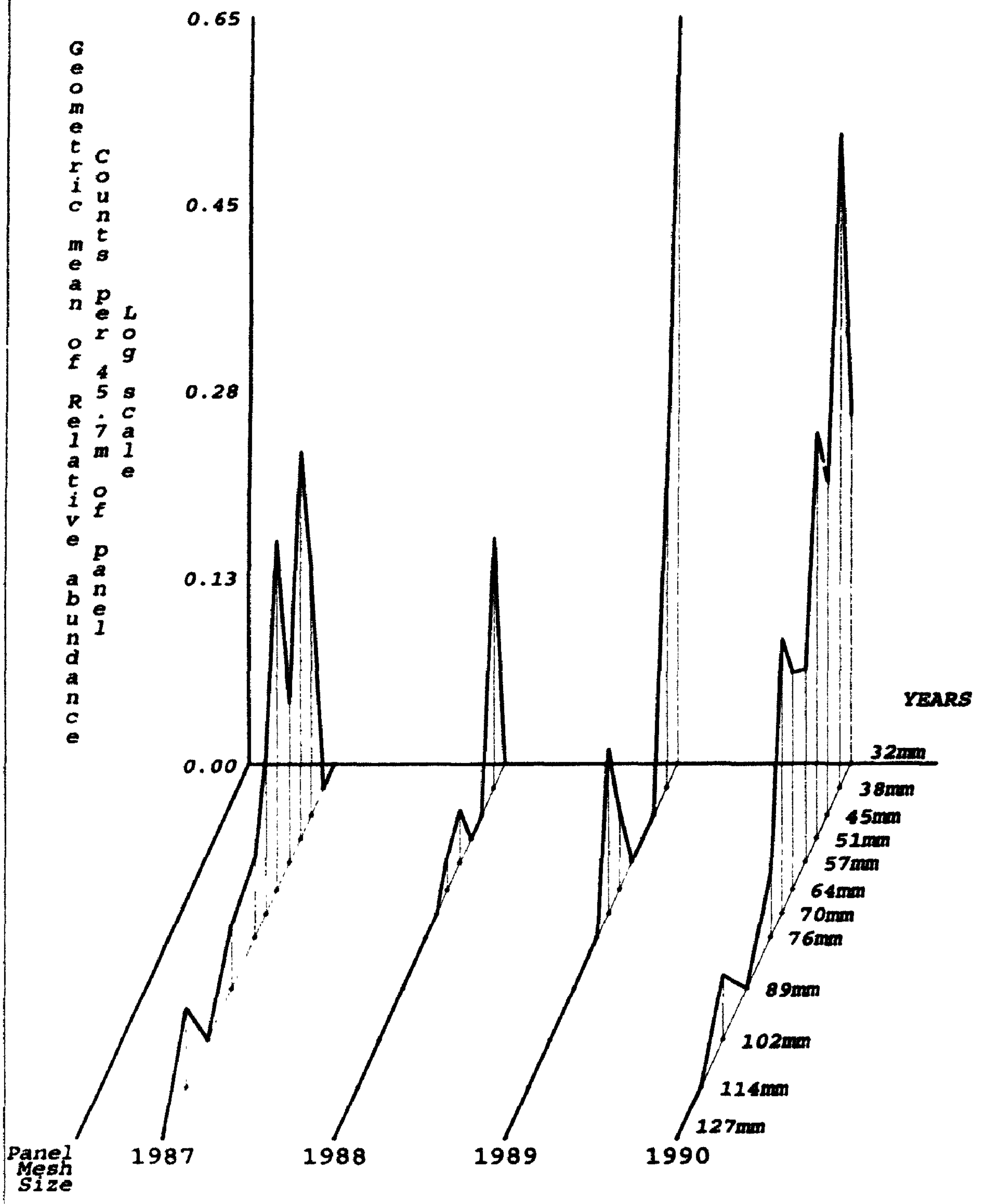


Figure 14a. Annual relative abundances in the Western basin of white bass by mesh size. Between years perspective.

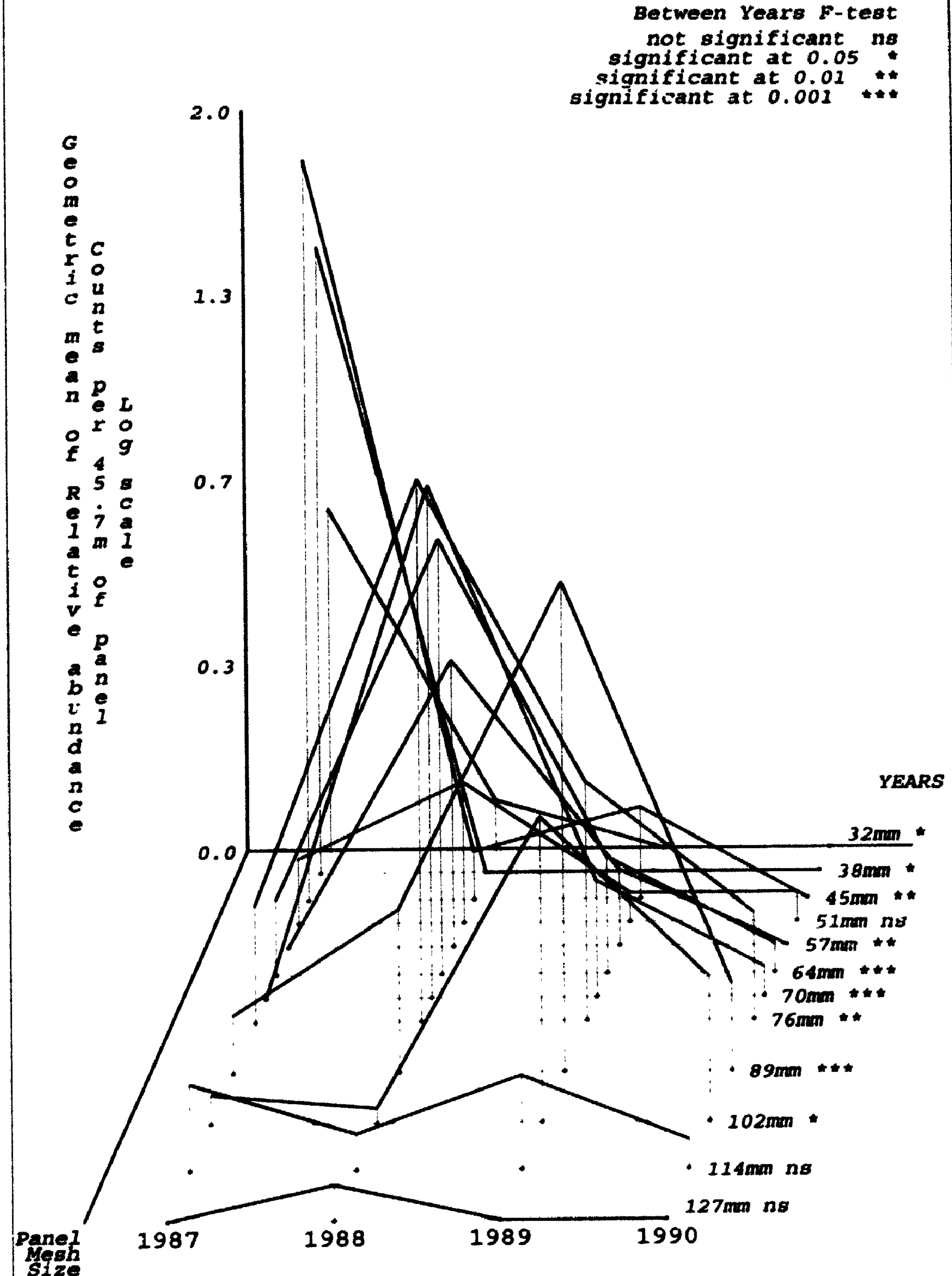


Figure 14b. Annual relative abundances in the Western basin of white bass by mesh size. Between mesh sizes perspective.

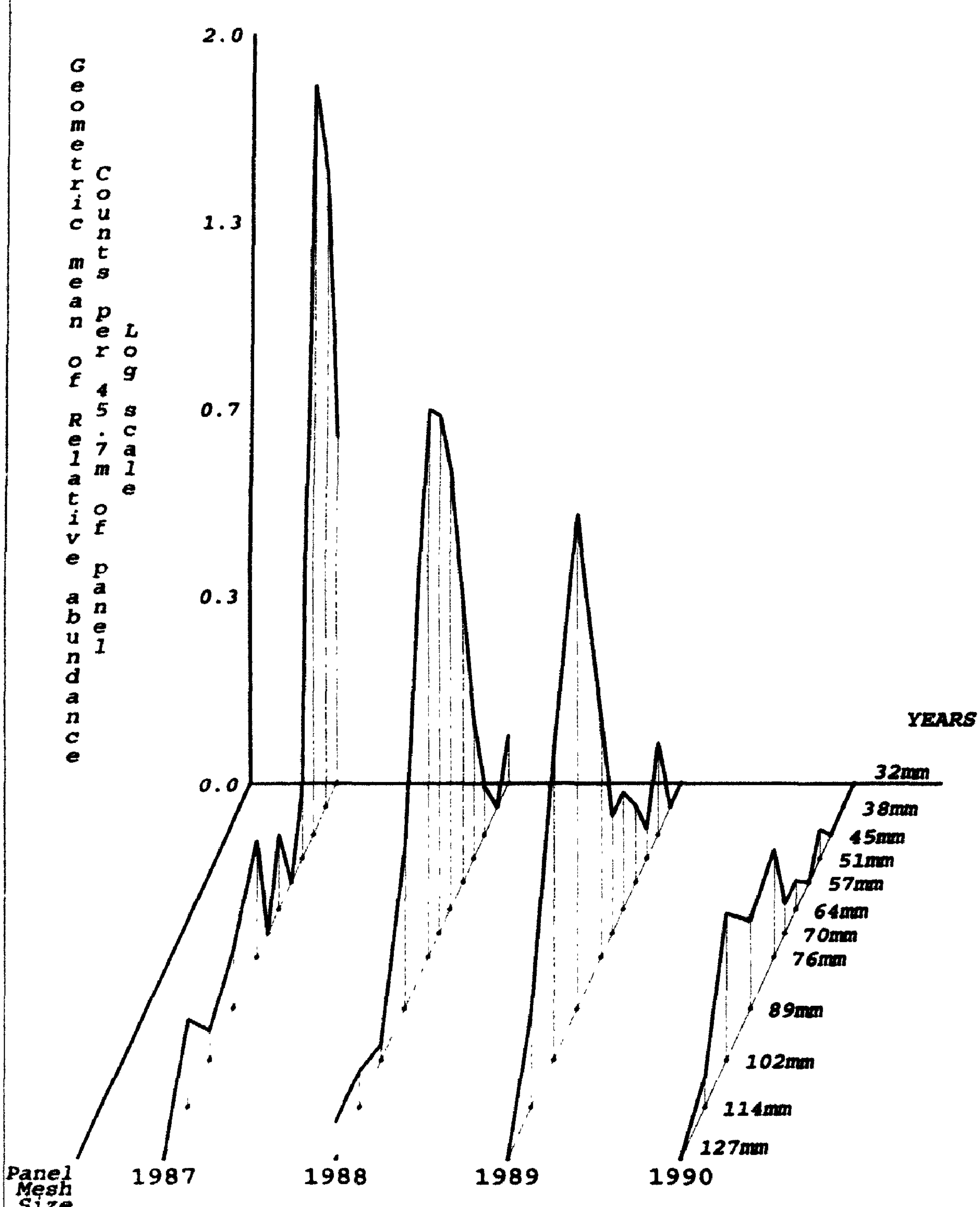


Figure 15a. Annual relative abundances in the Western basin of silver chub by mesh size. Between years perspective.

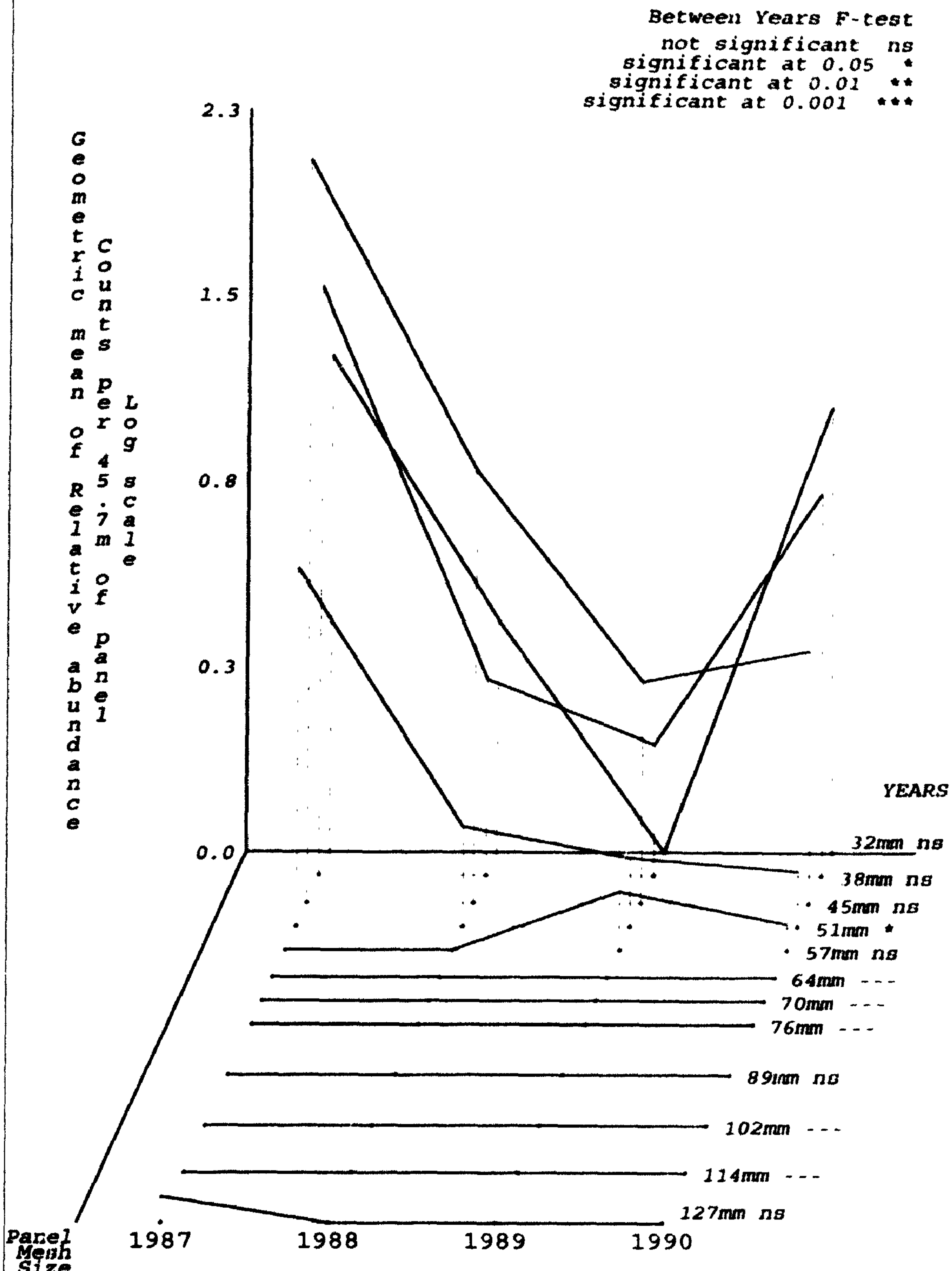


Figure 15b. Annual relative abundances in the Western basin of silver chub by mesh size. Between mesh sizes perspective.

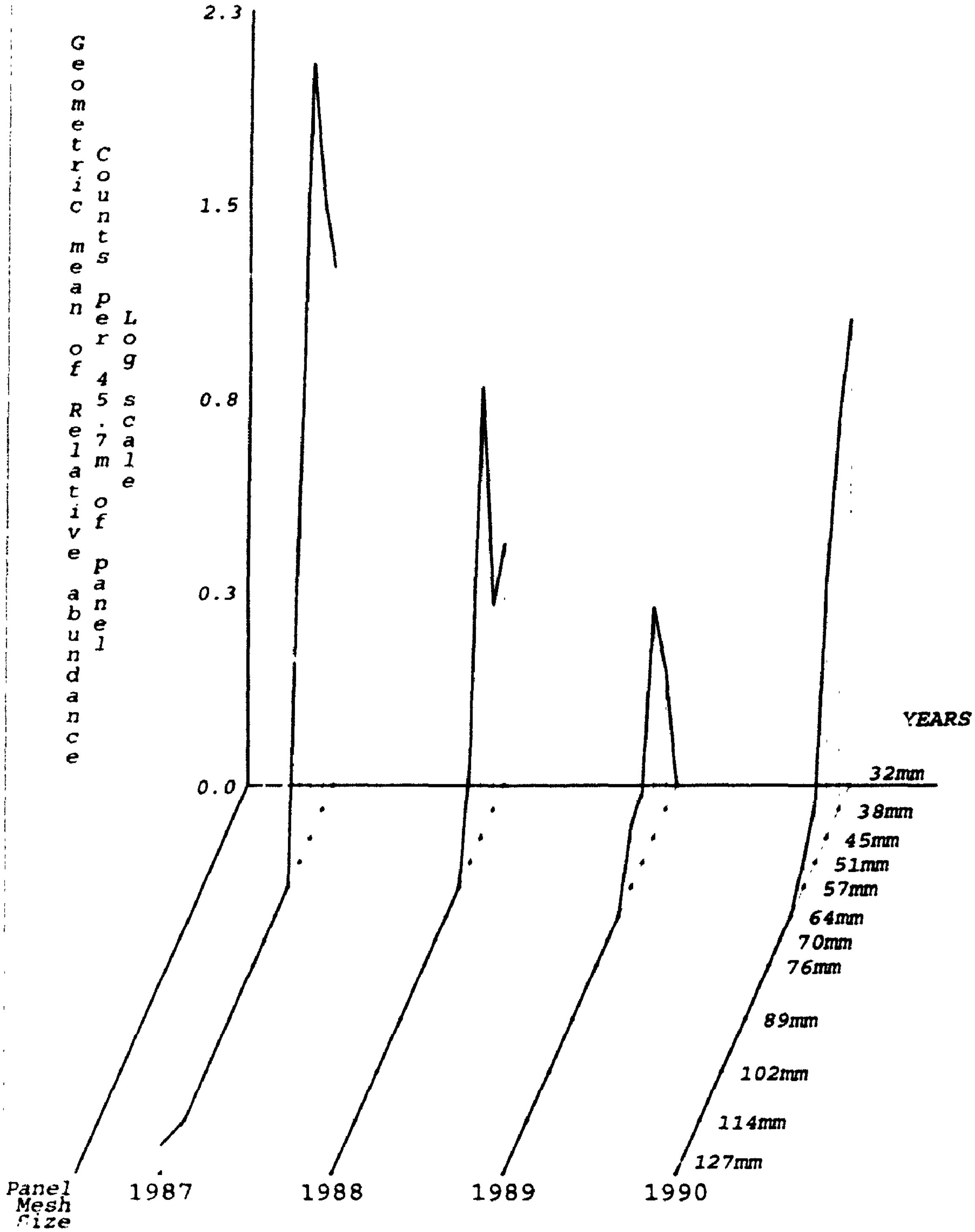


Figure 16a. Annual relative abundances in the Western basin of spottail shiner by mesh size. Between years perspective.

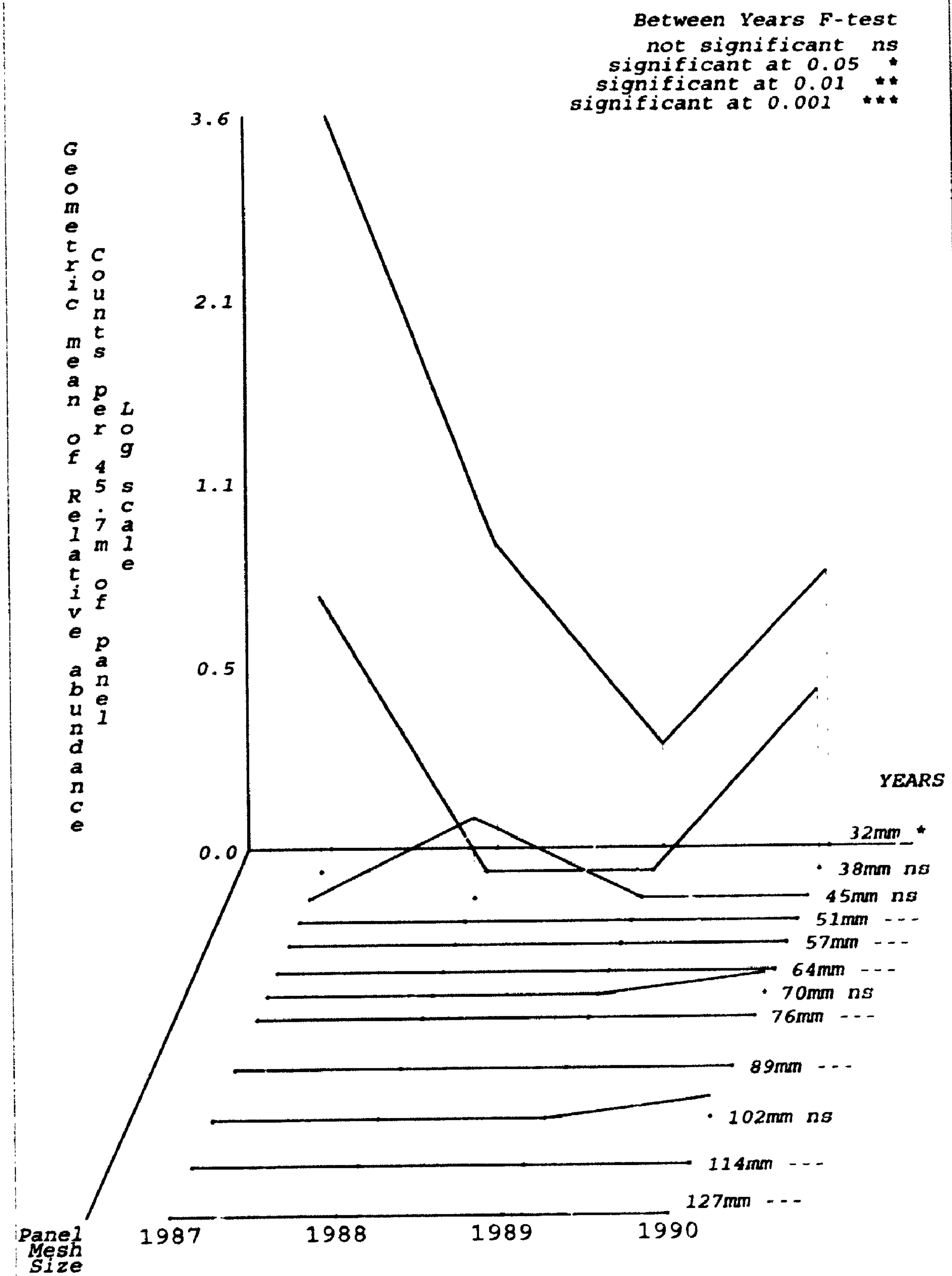


Figure 16b. Annual relative abundances in the Western basin of spottail shiner by mesh size. Between mesh sizes perspective.

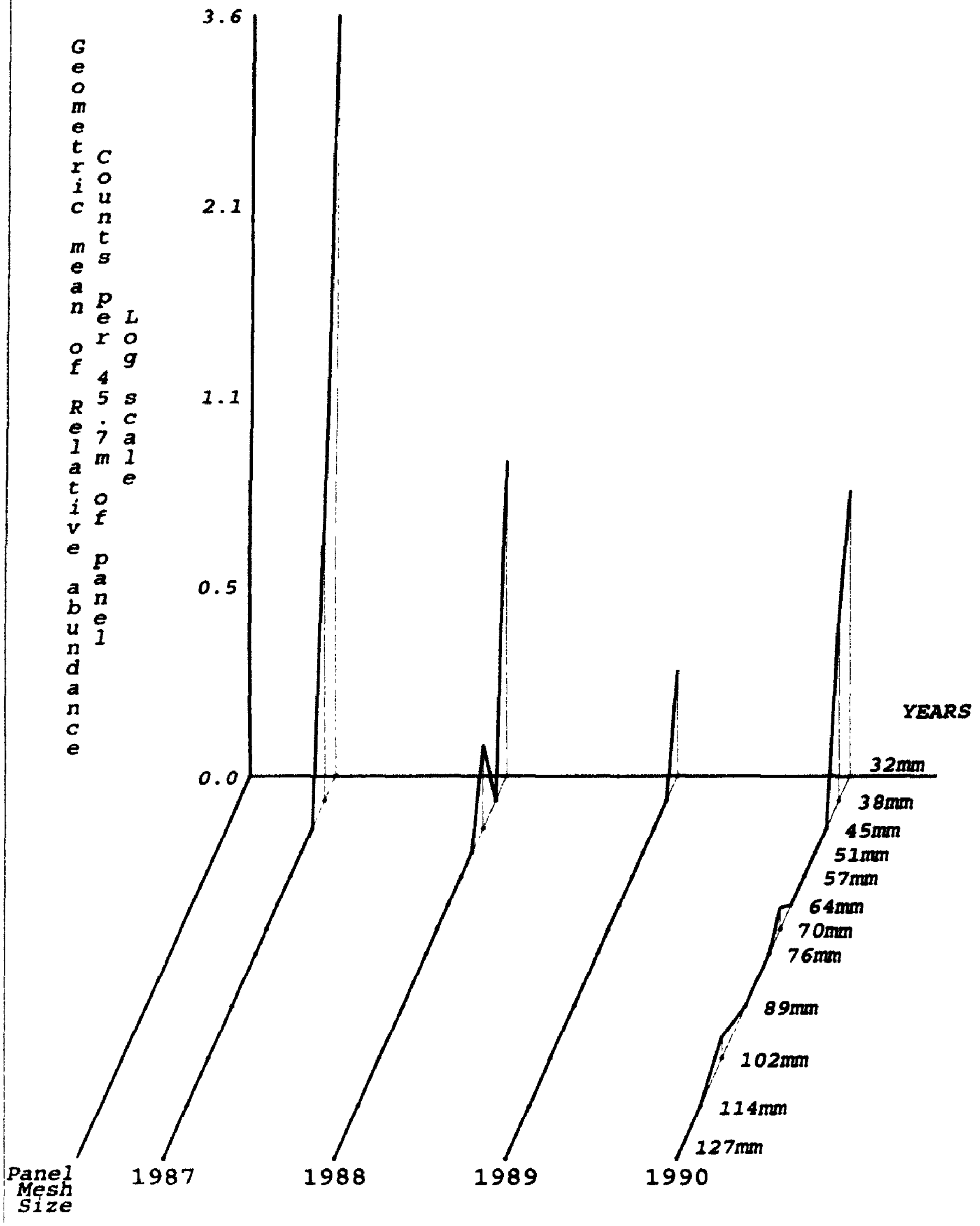


Figure 17a. Annual relative abundances in the Western basin of troutperch by mesh size. Between years perspective.

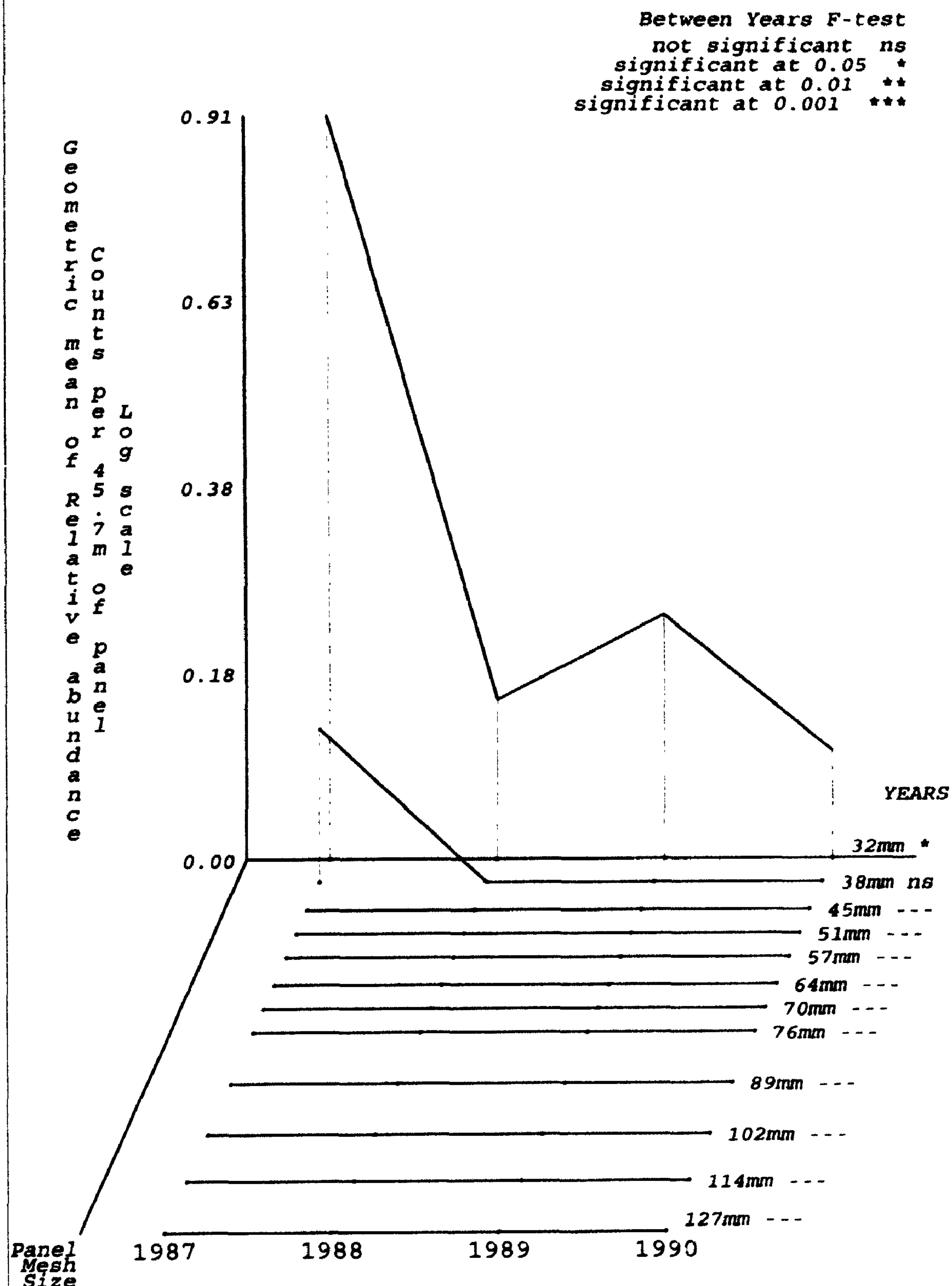


Figure 17b. Annual relative abundances in the Western basin of troutperch by mesh size. Between mesh sizes perspective.

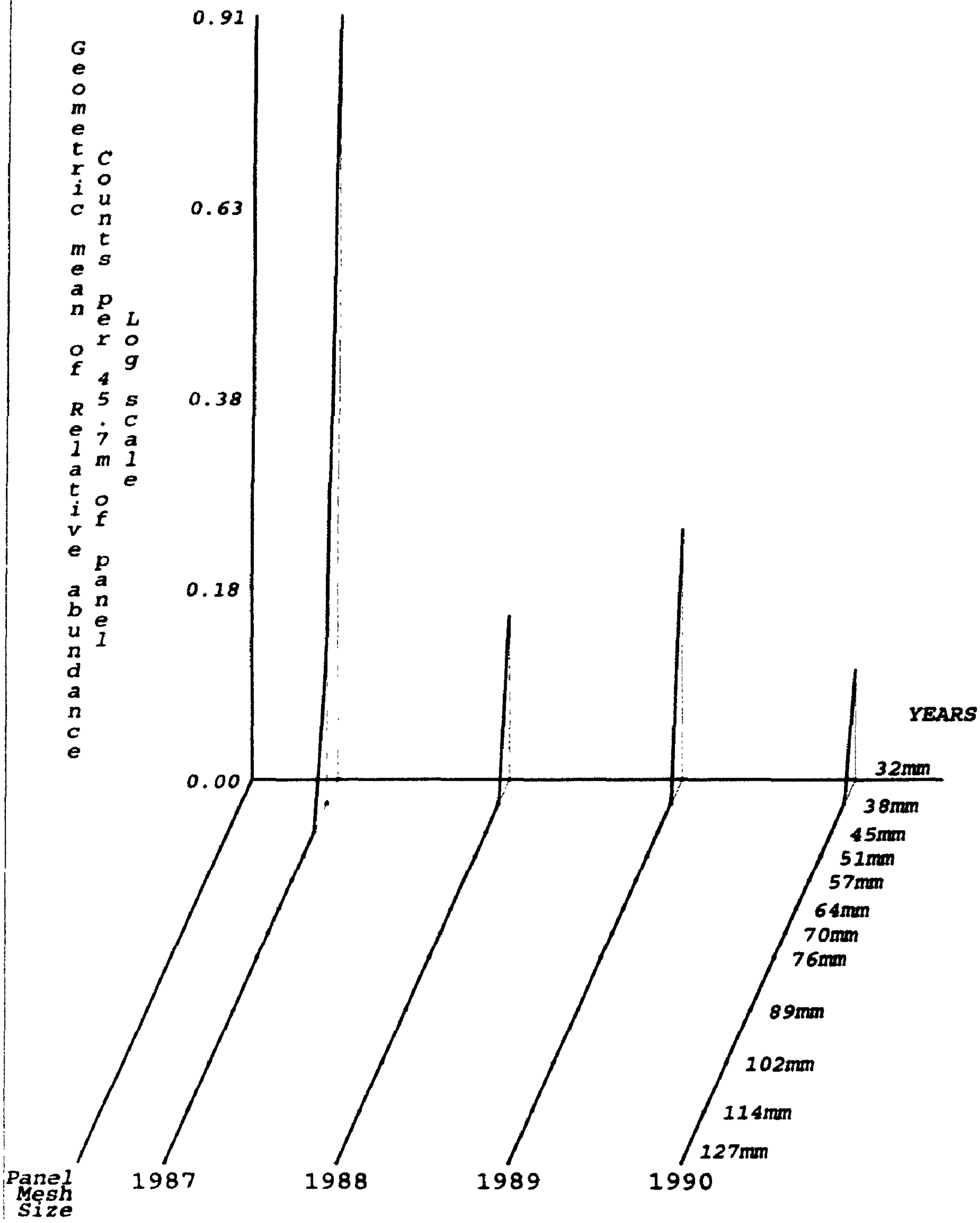


Figure 18a. Annual relative abundances in the Western basin of channel catfish by mesh size. Between years perspective.

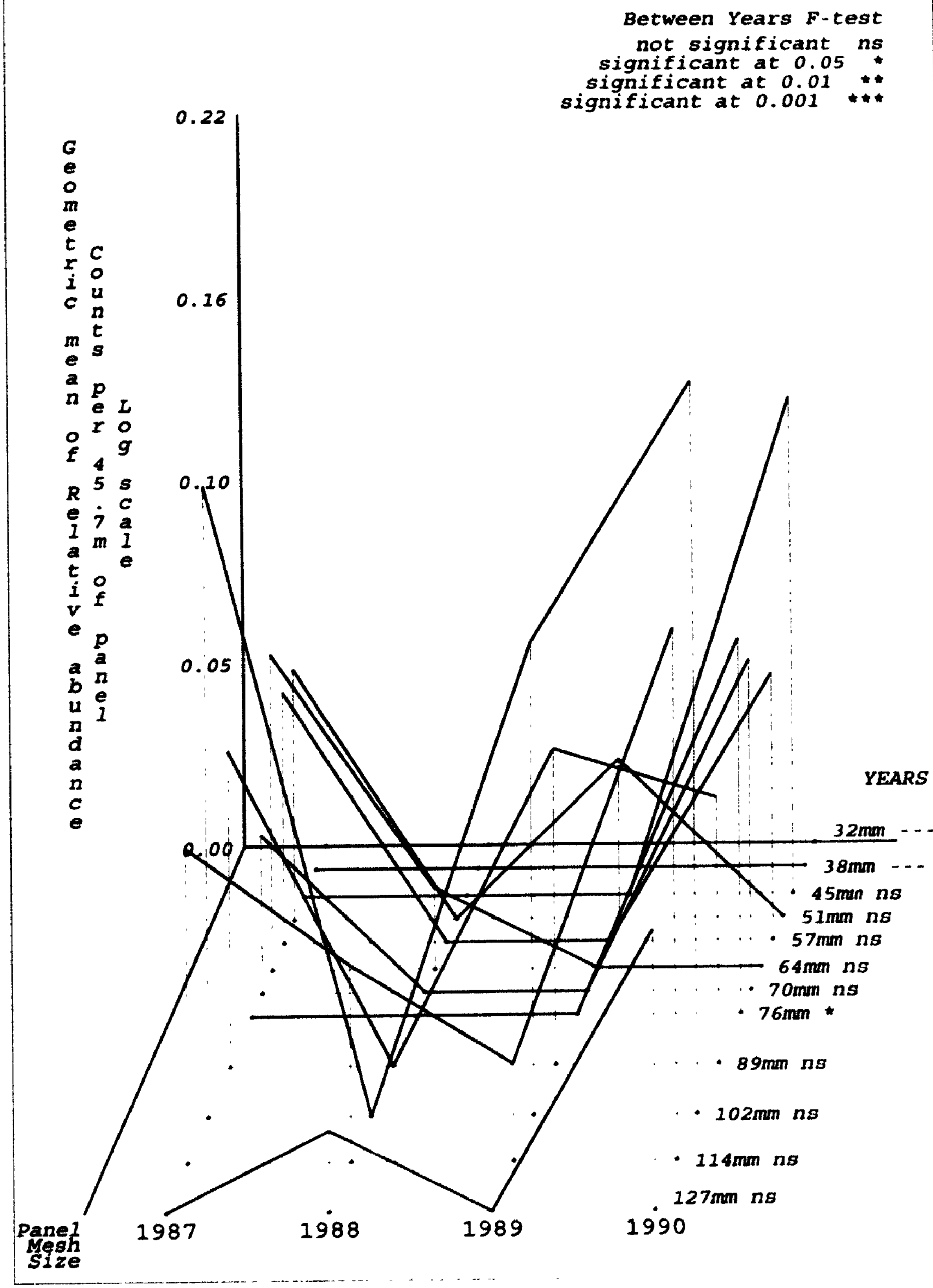


Figure 18b. Annual relative abundances in the Western basin of channel catfish by mesh size. Between mesh sizes perspective.

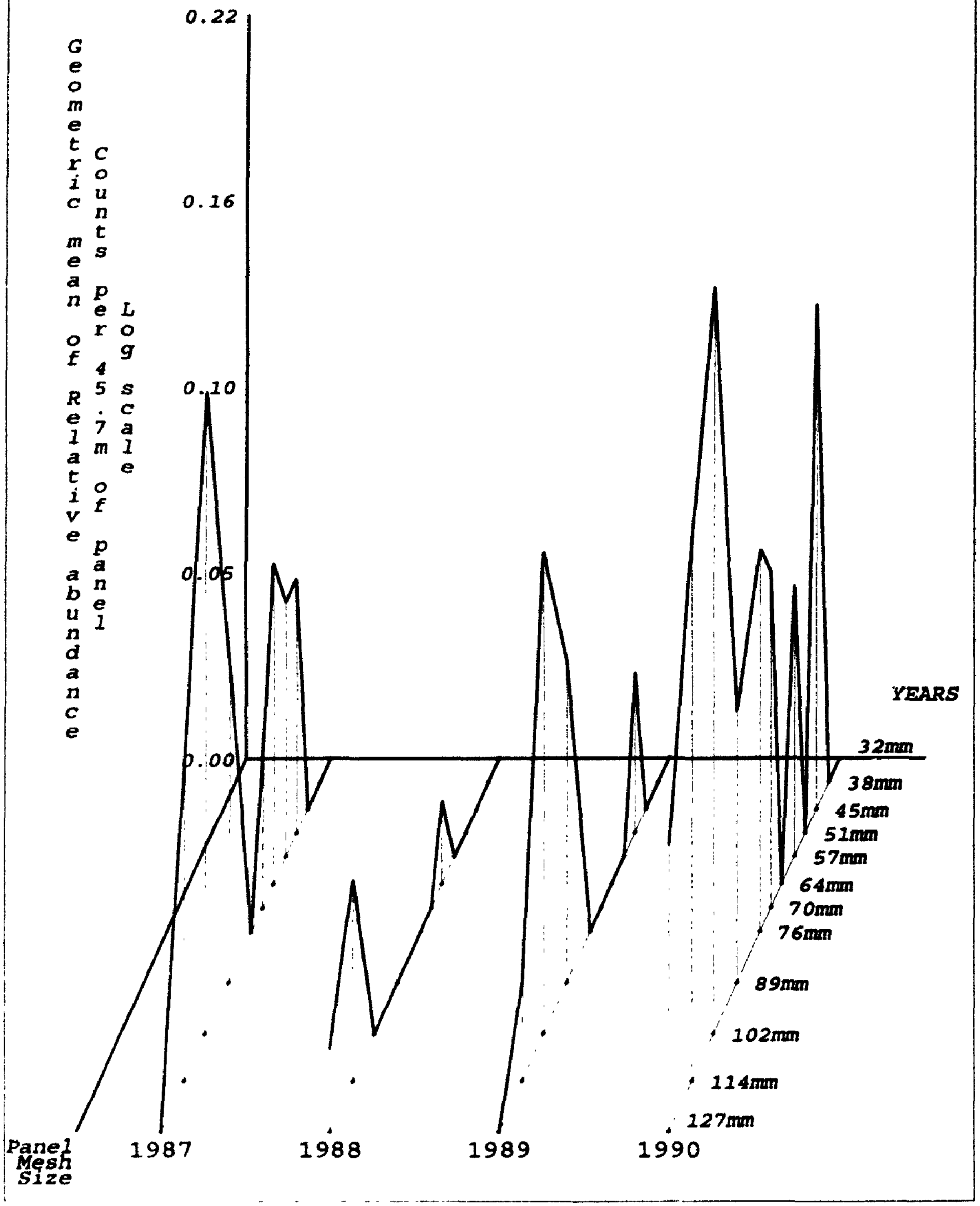


Figure 19a. Annual relative abundances in the West-Central basin of white perch by mesh size. Between years perspective.

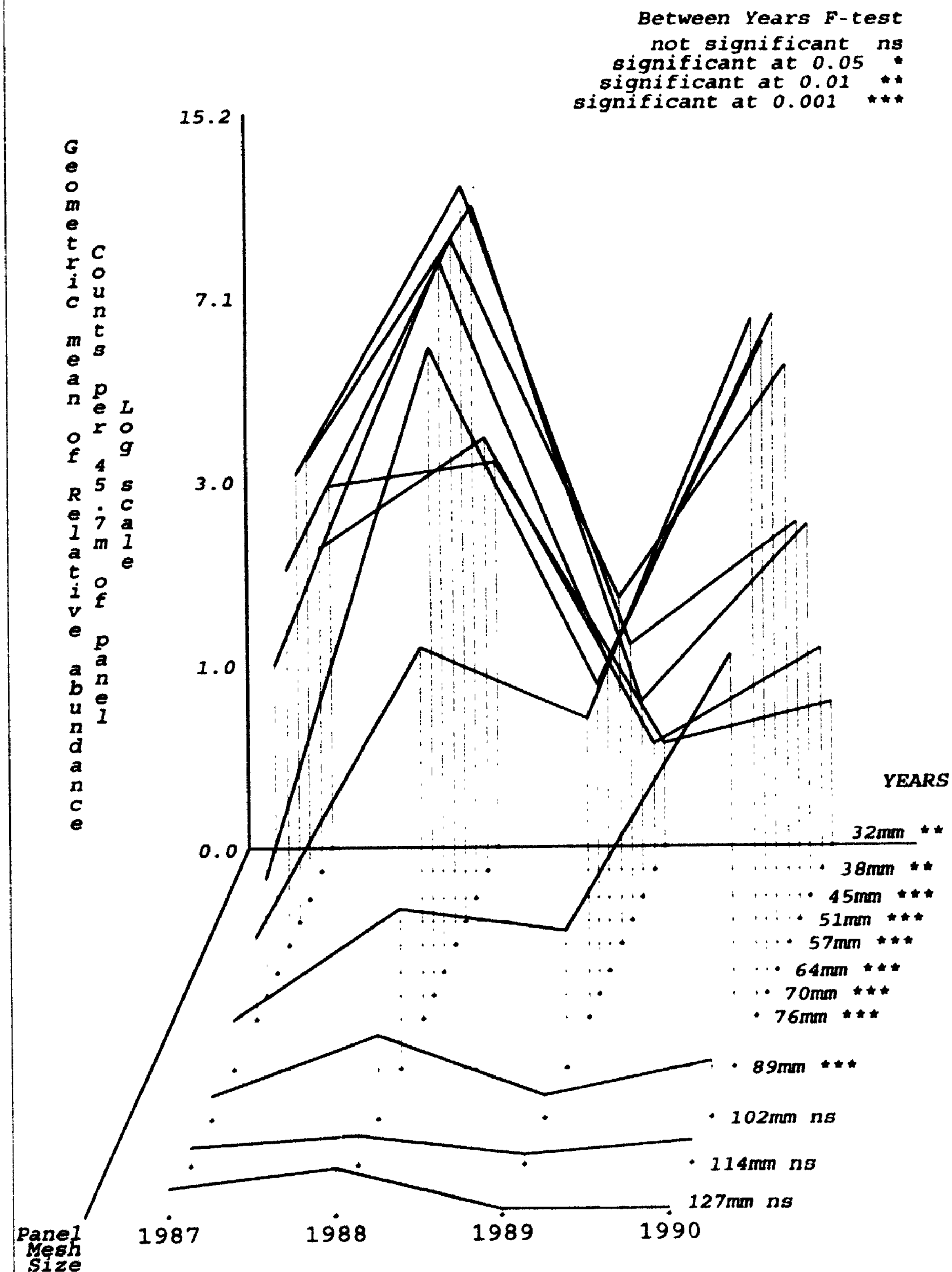


Figure 19b. Annual relative abundances in the West-Central basin of white perch by mesh size. Between mesh sizes perspective.

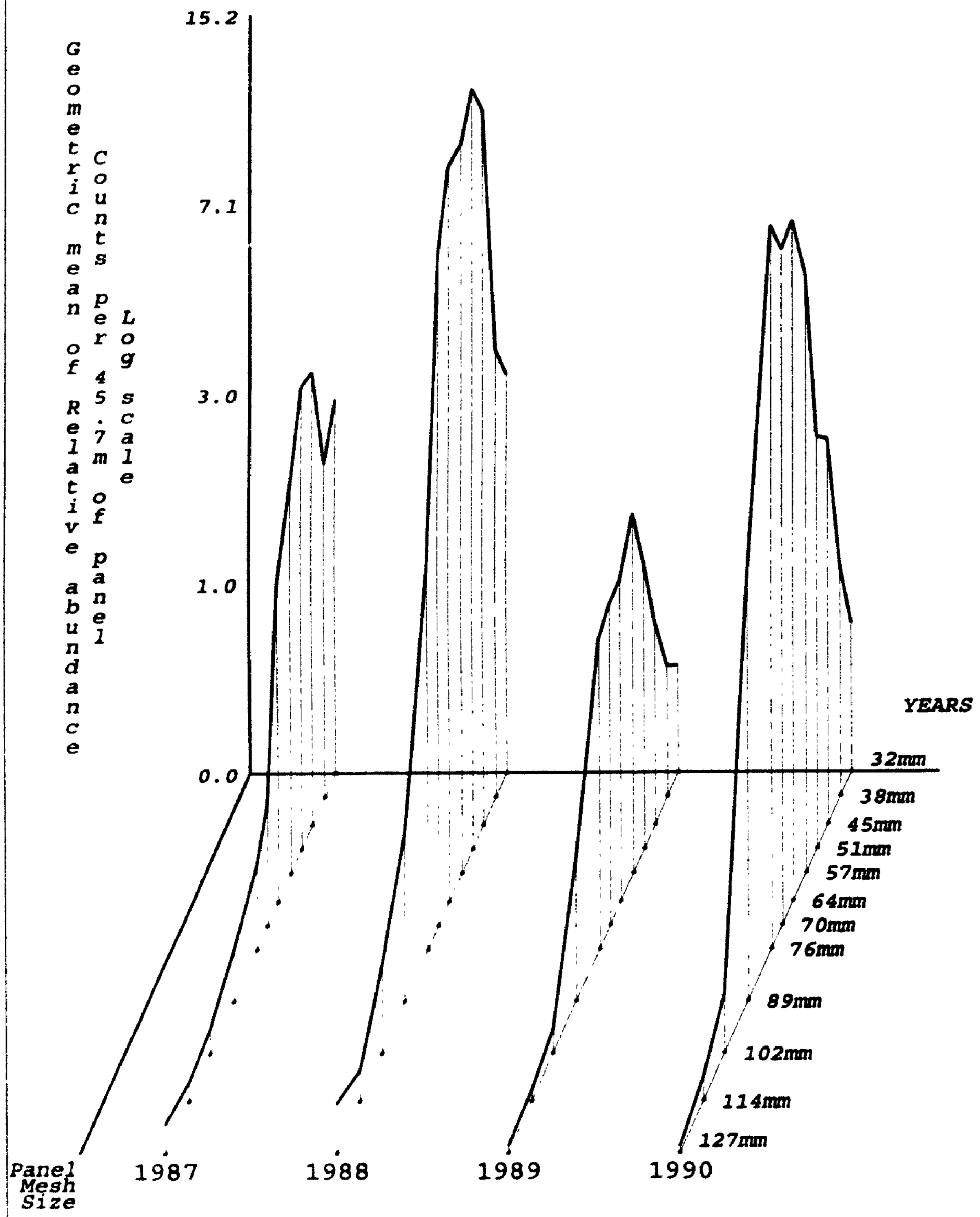


Figure 20a. Annual relative abundances in the West-Central basin of yellow perch by mesh size. Between years perspective.

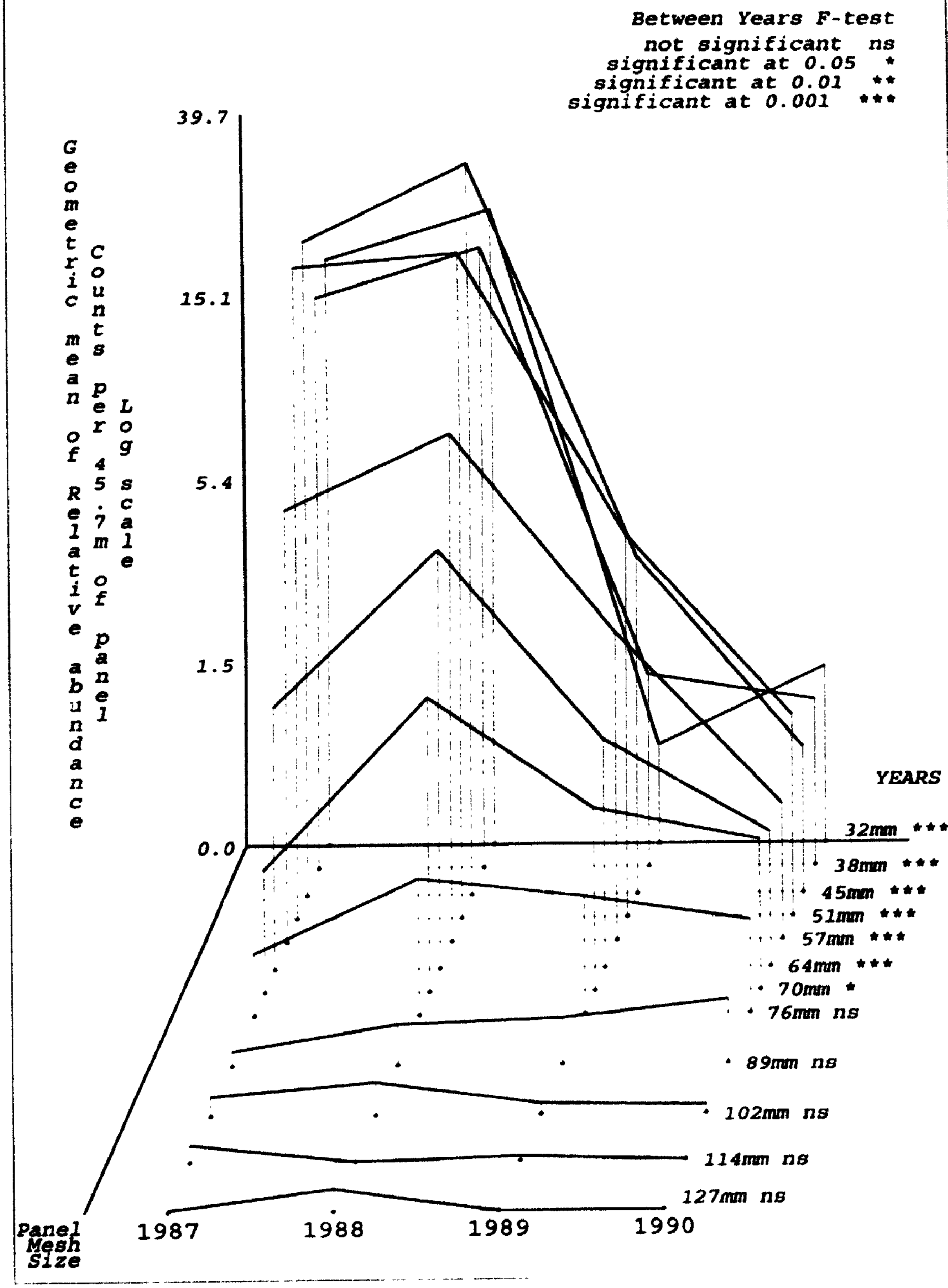


Figure 20b. Annual relative abundances in the West-Central basin of yellow perch by mesh size. Between mesh sizes perspective.

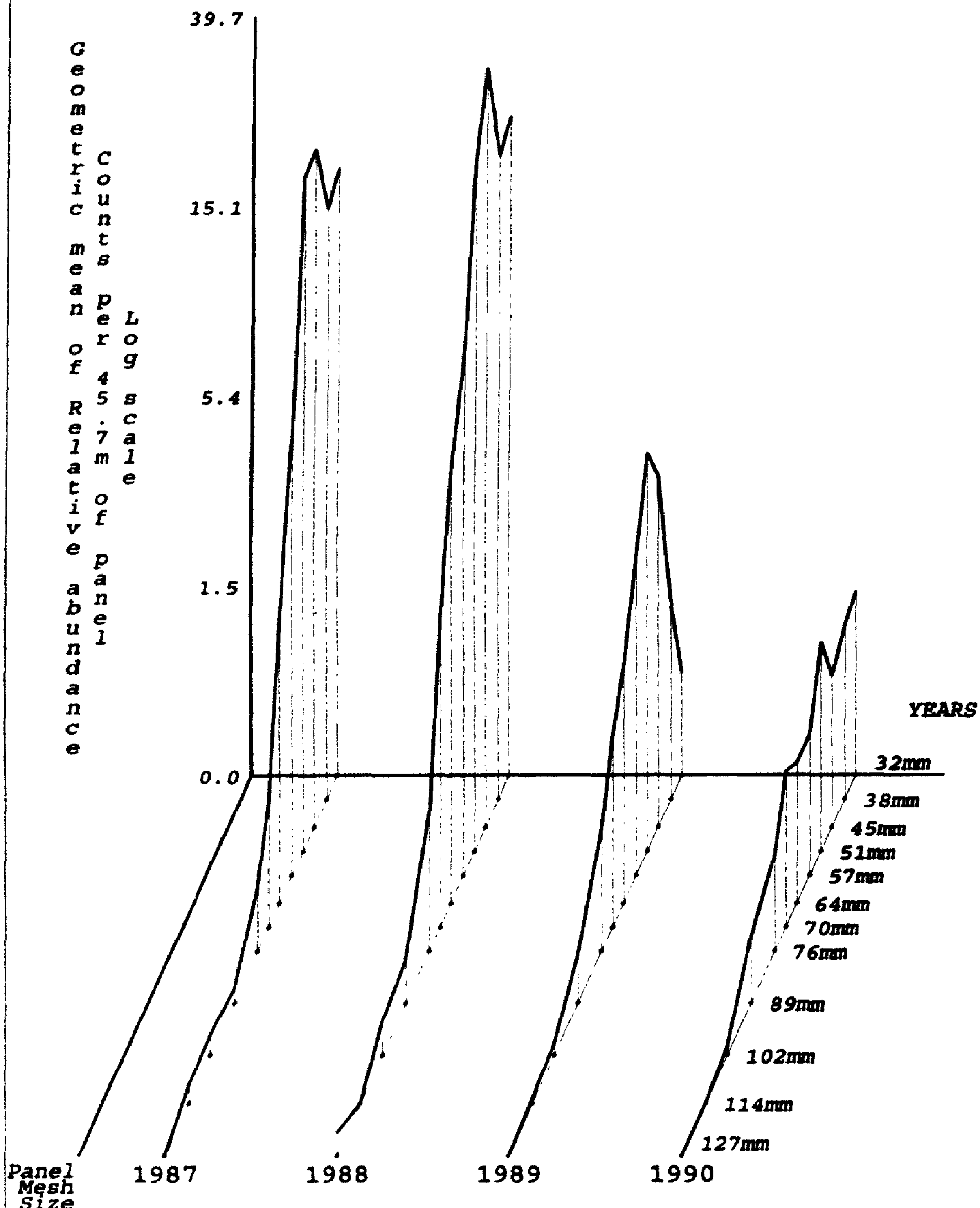


Figure 21a. Annual relative abundances in West-Central basin of freshwater drum by mesh size. Between years perspective.

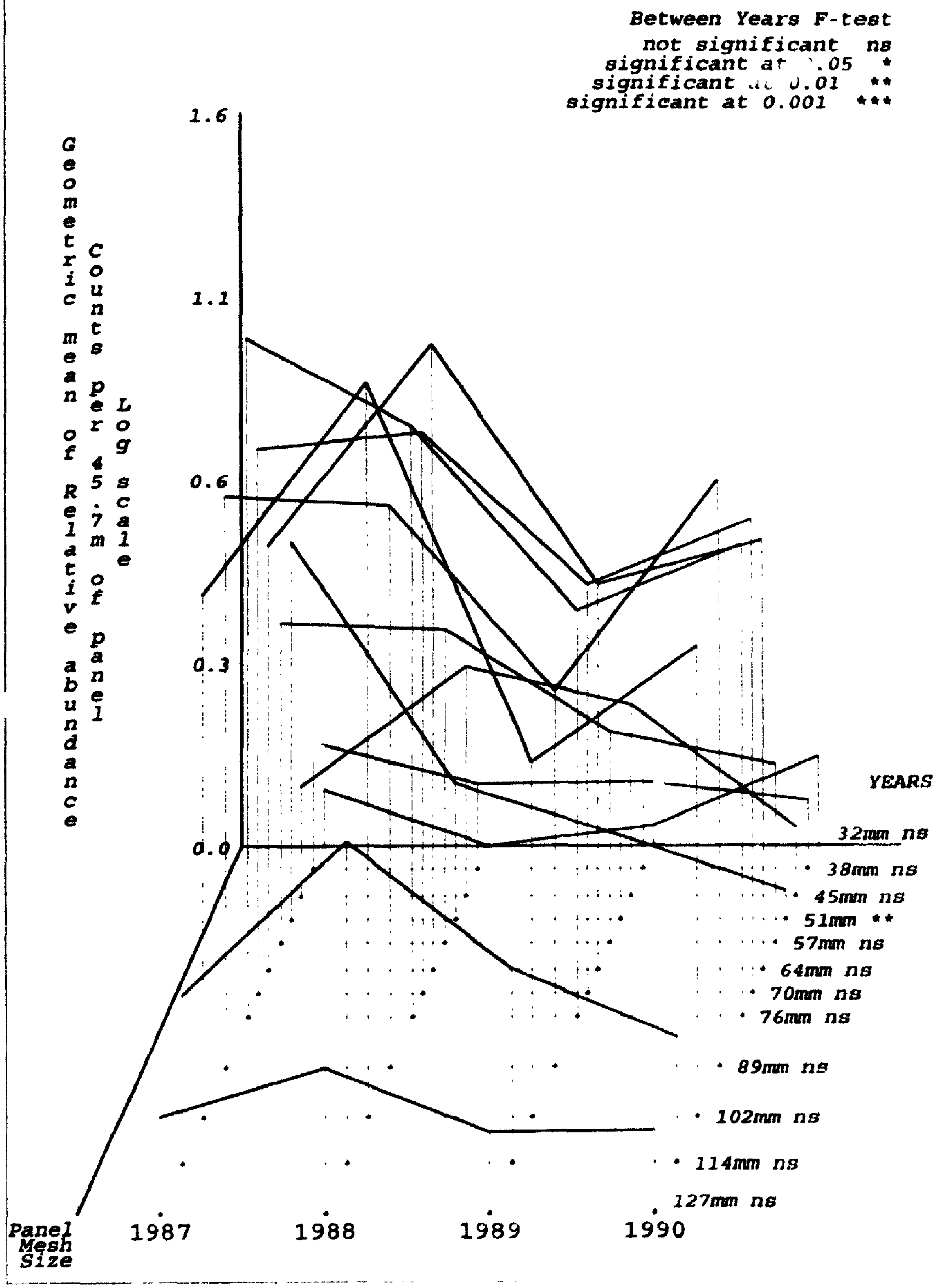


Figure 21b. Annual relative abundances in West-Central basin of freshwater drum by mesh size. Between mesh sizes perspective.

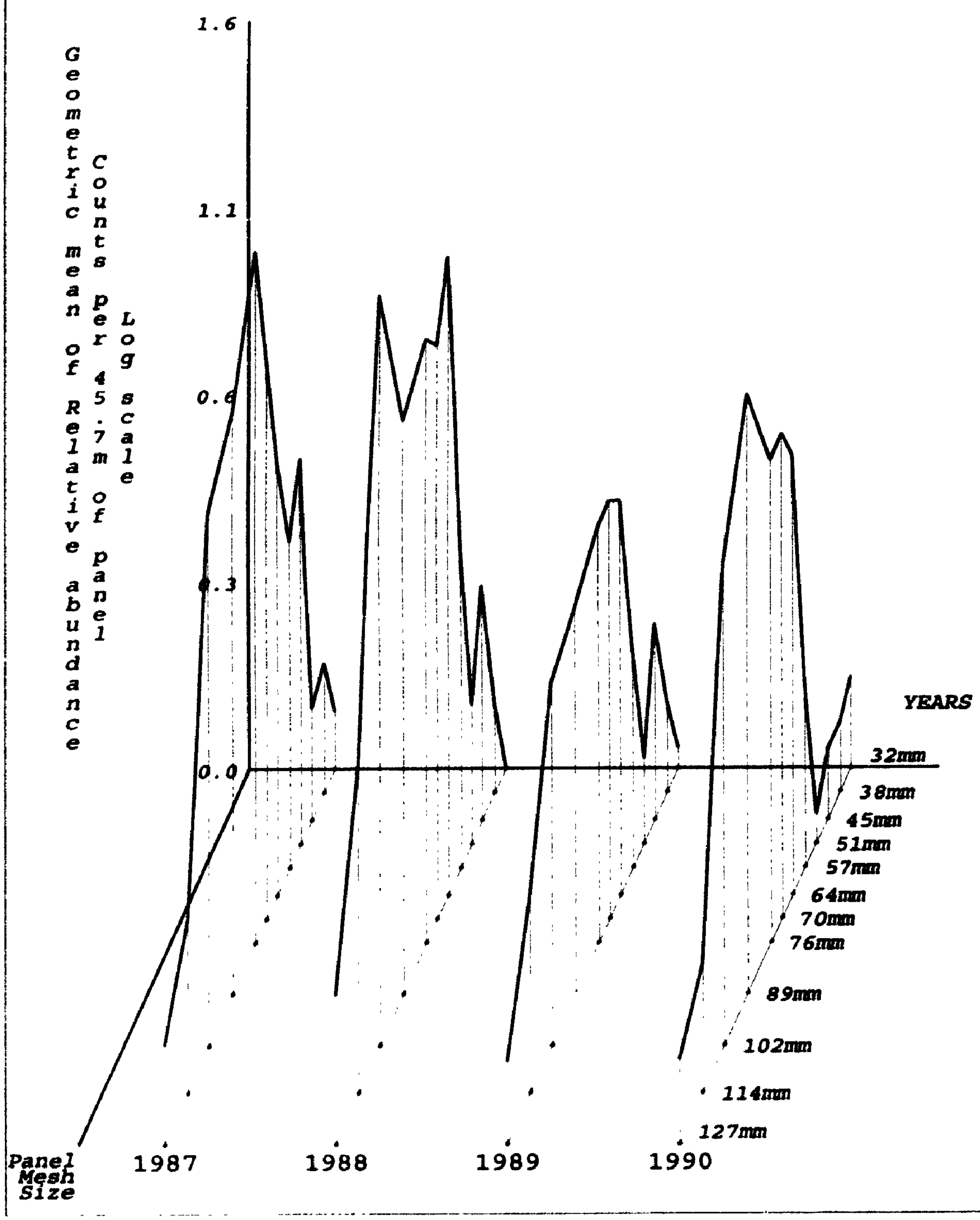


Figure 22a. Annual relative abundances in the West-Central basin of alewife by mesh size. Between years perspective.

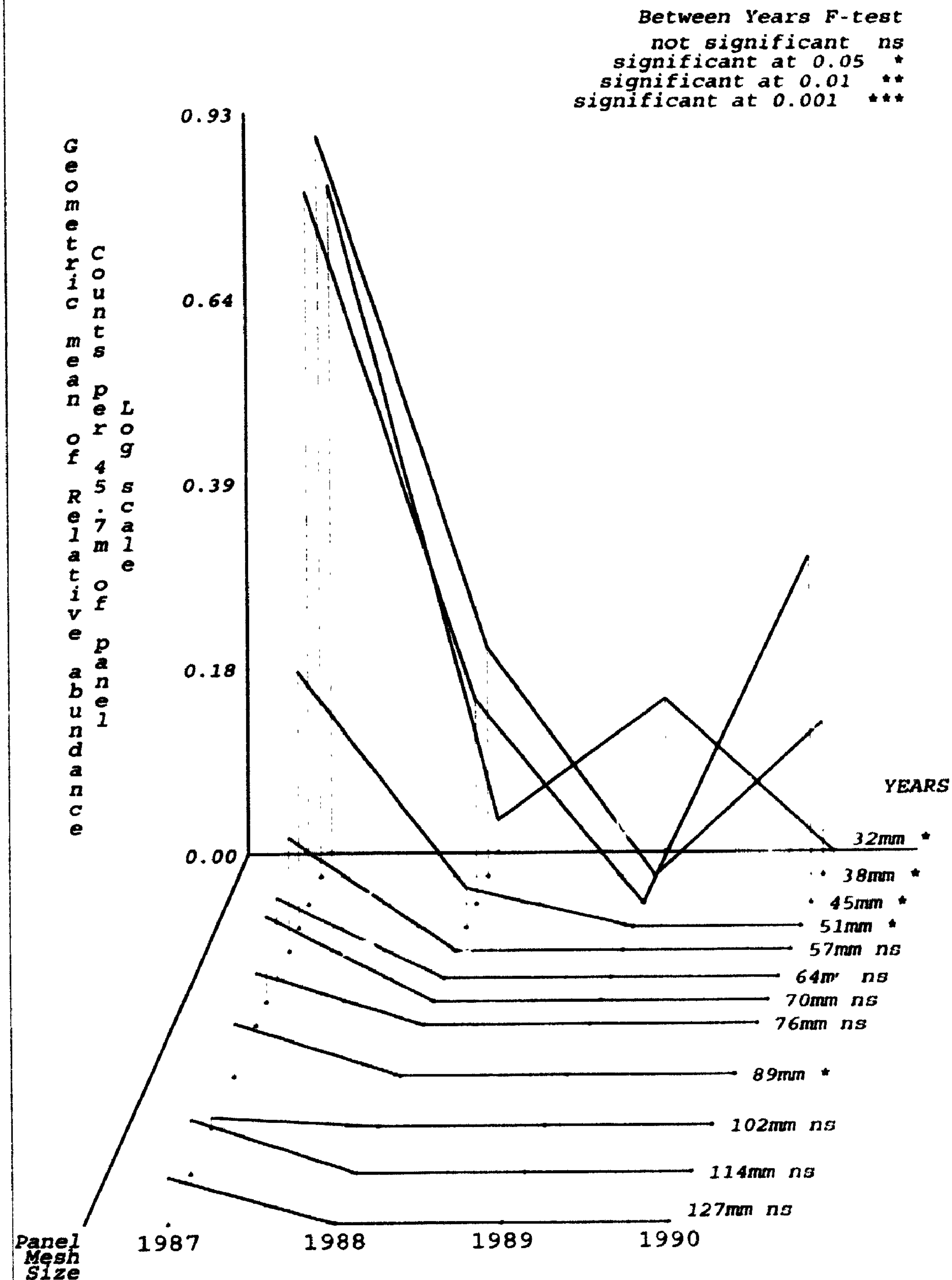


Figure 22b. Annual relative abundances in the West-Central basin of alewife by mesh size. Between mesh sizes perspective.

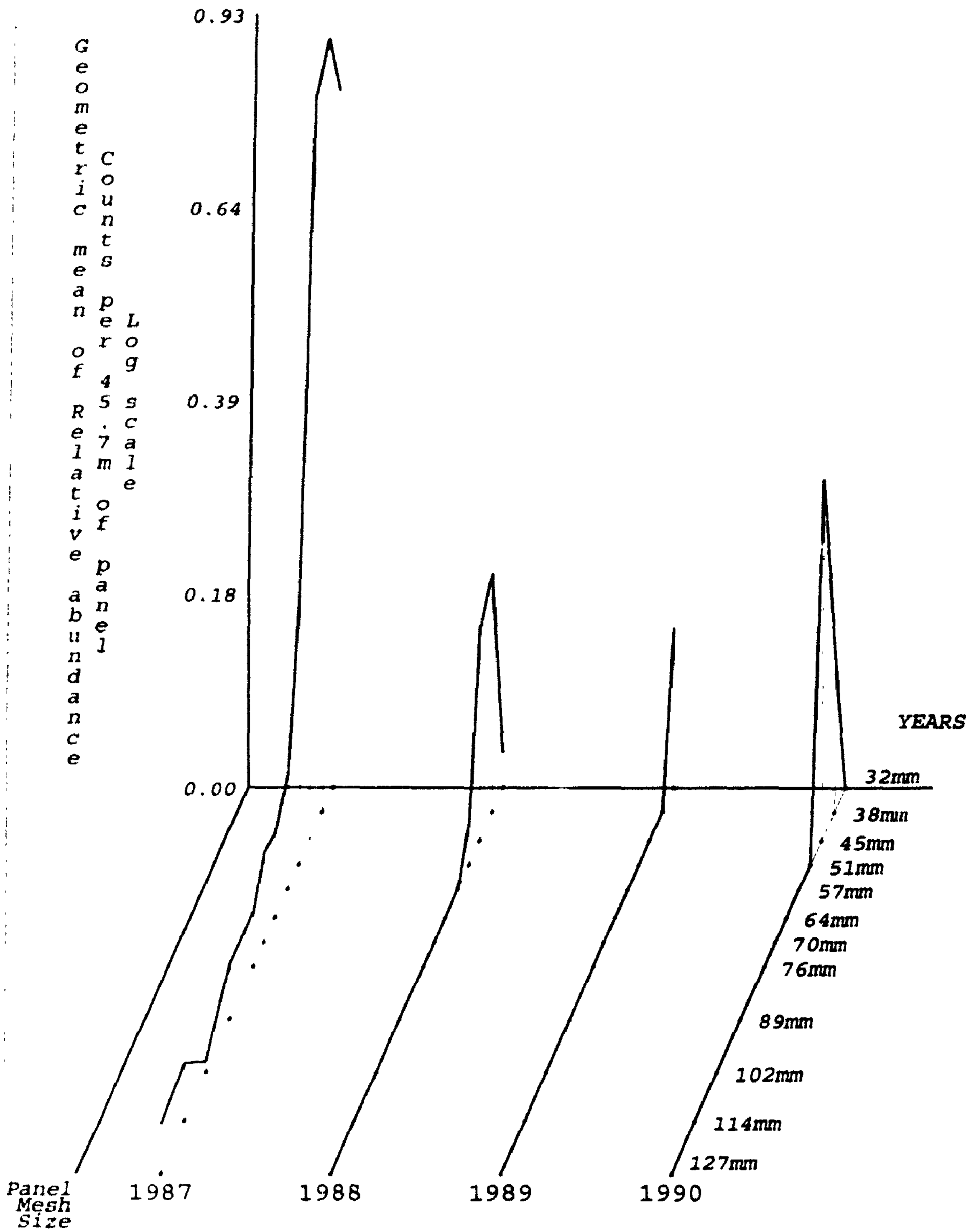


Figure 23a. Annual relative abundances in the West-Central basin of walleye by mesh size. Between years perspective.

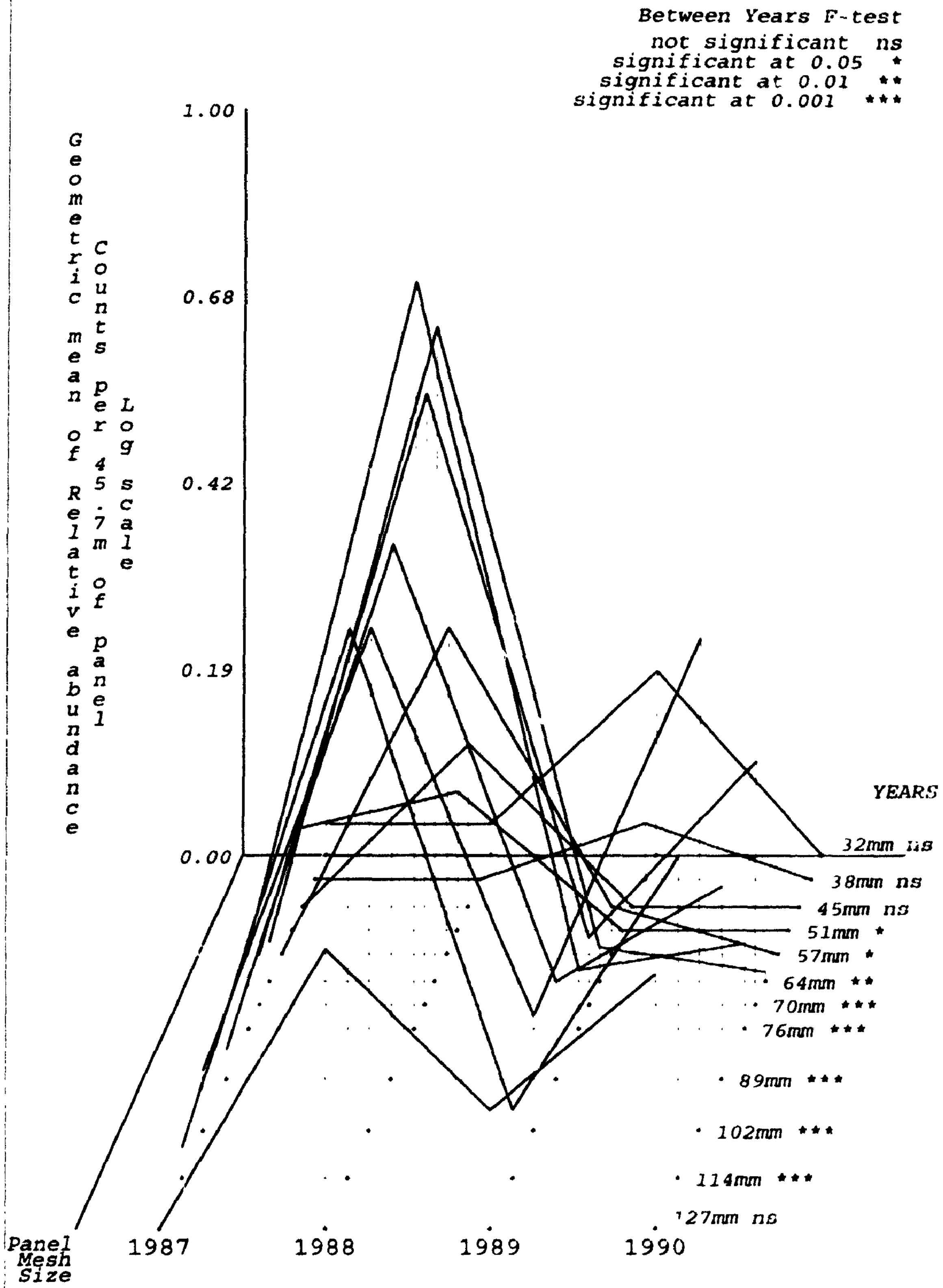


Figure 23b. Annual relative abundances in the West-Central basin of walleye by mesh size. Between mesh sizes perspective.

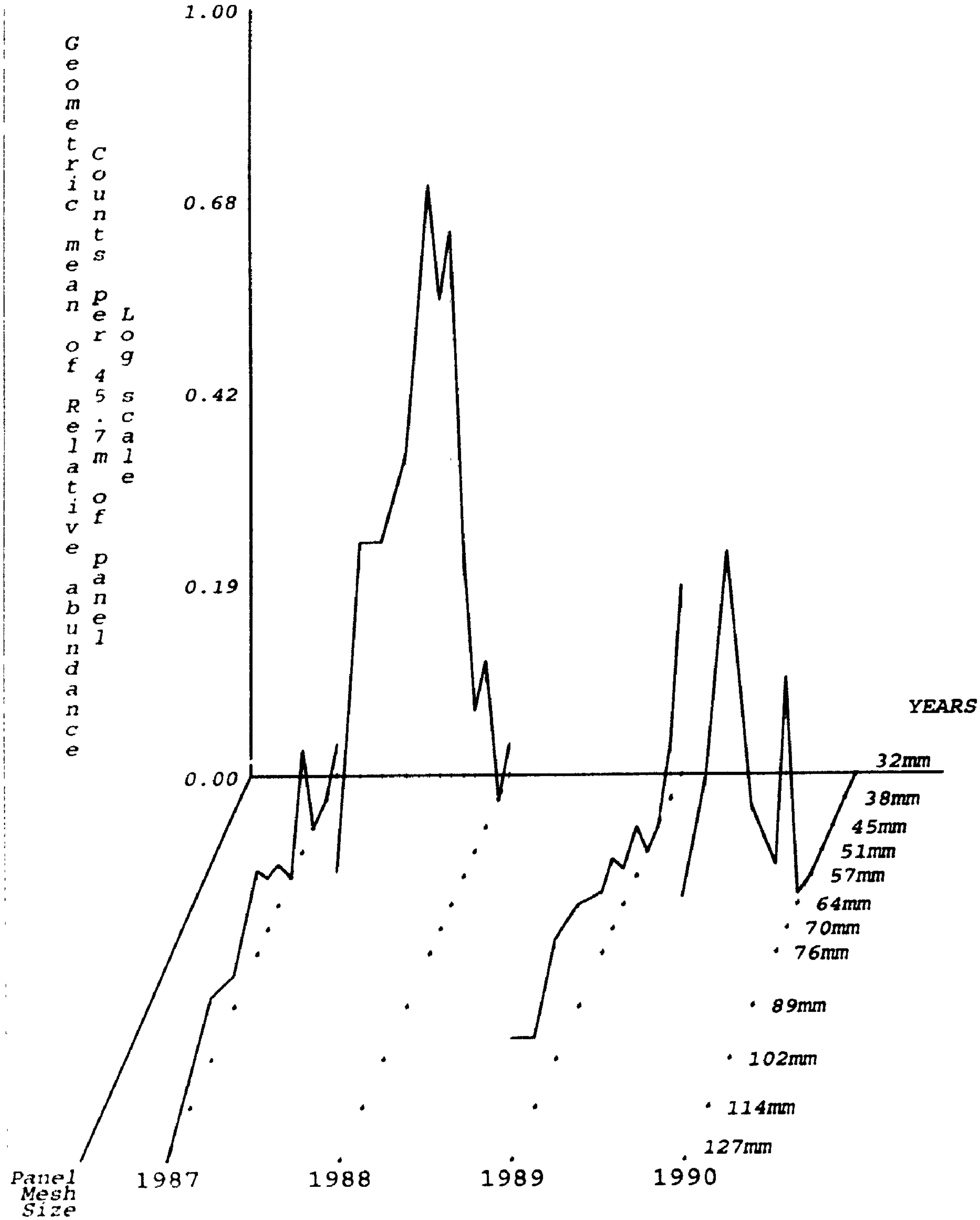


Figure 24a. Annual relative abundances in the West-Central basin of rainbow smelt by mesh size. Between years perspective.

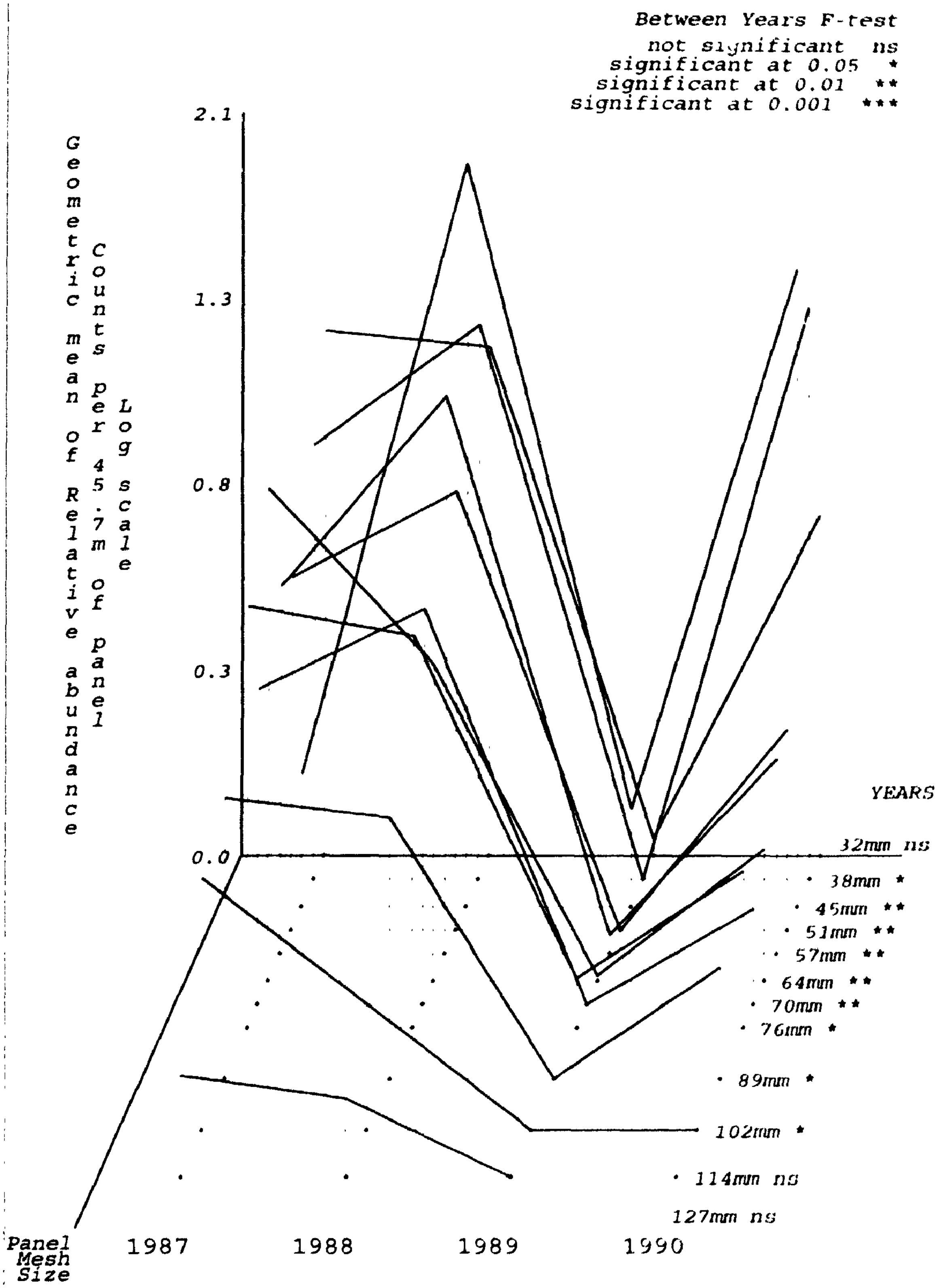


Figure 24b. Annual relative abundances in the West-Central basin of rainbow smelt by mesh size. Between mesh sizes perspective.

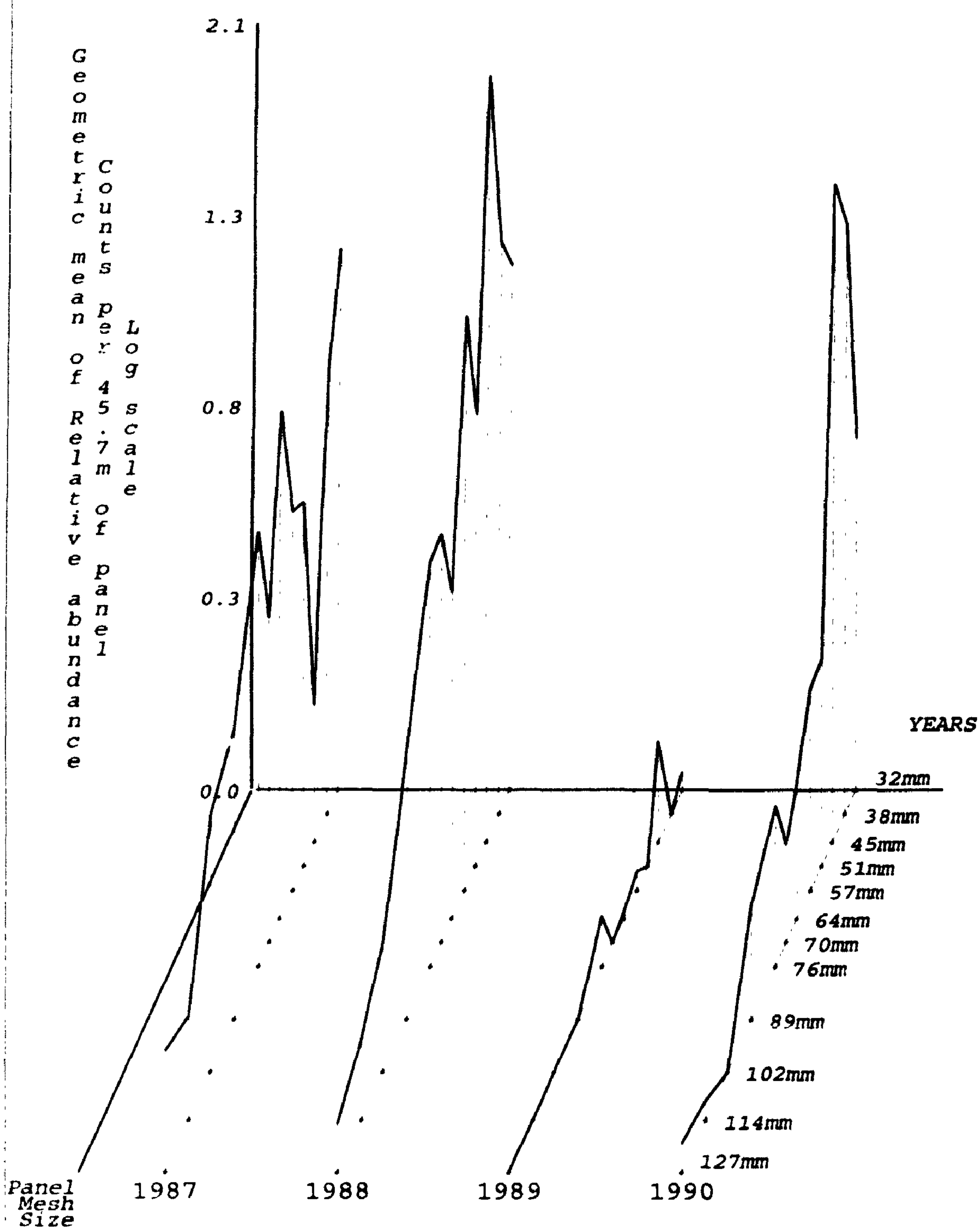


Figure 25a. Annual relative abundances in the West-Central basin of white bass by mesh size. Between years perspective.

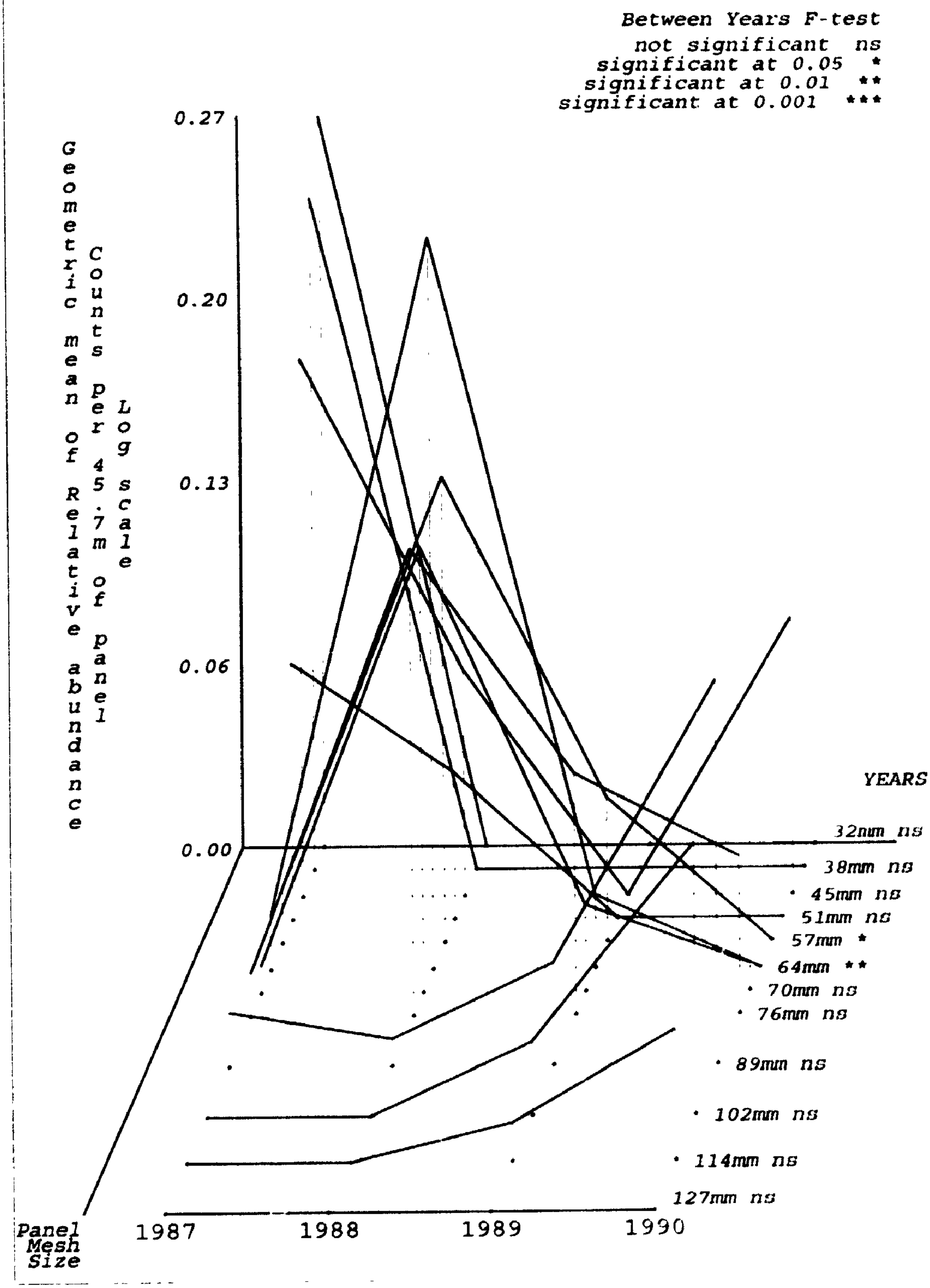


Figure 25b. Annual relative abundances in the West-Central basin of white bass by mesh size. Between mesh sizes perspective.

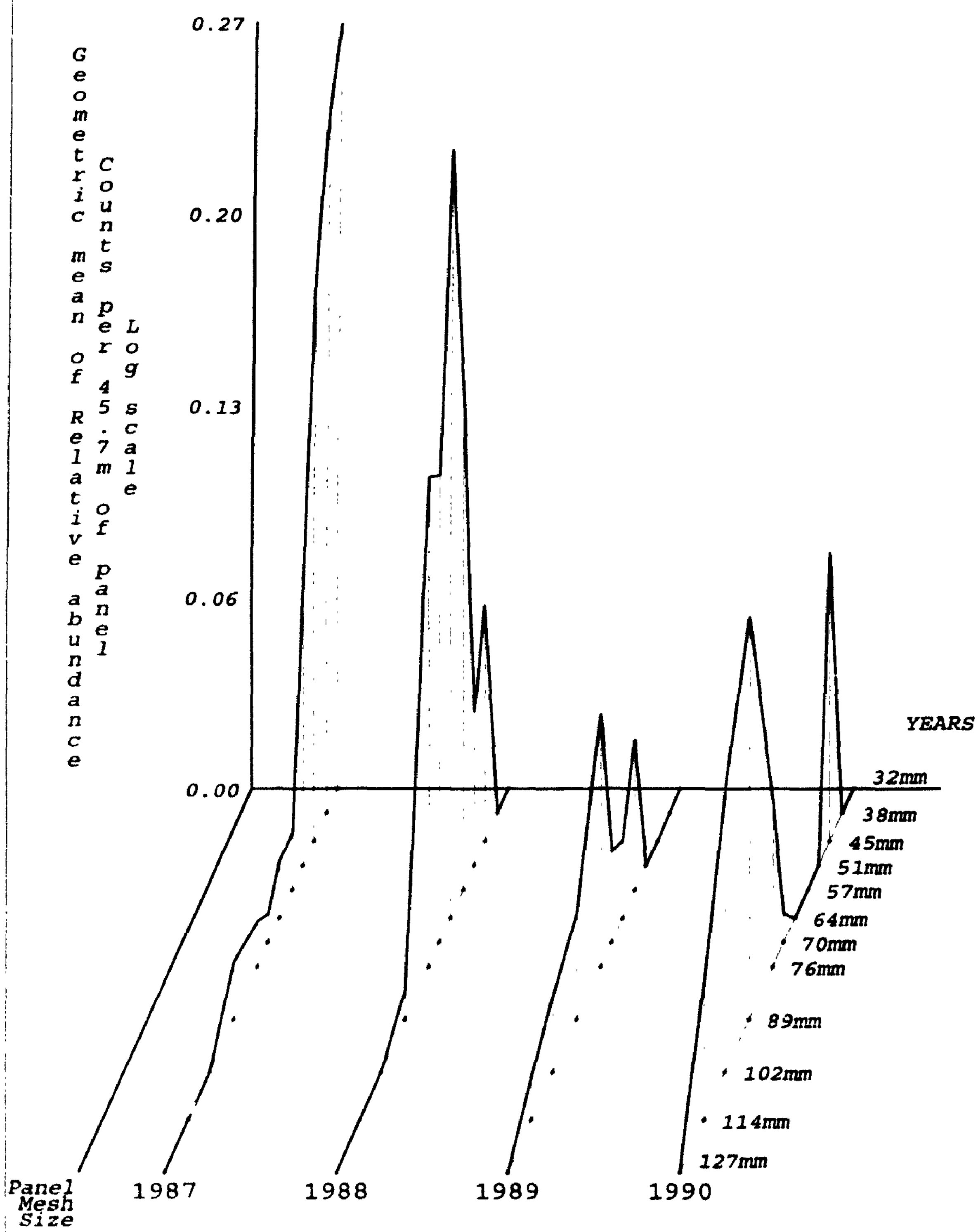


Figure 26a. Annual relative abundances in the West-Central basin of spottail shiner by mesh size. Between years perspective.

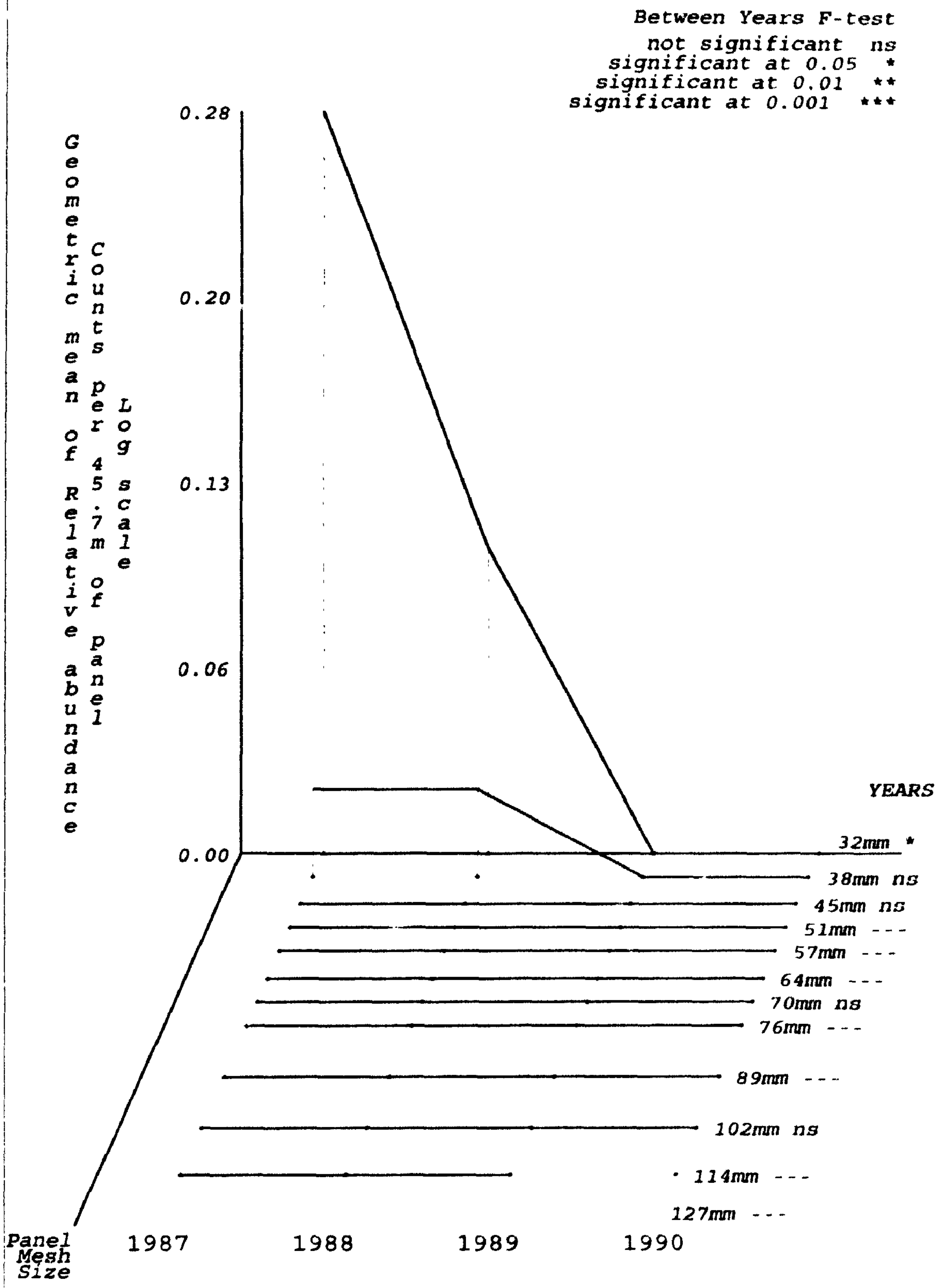


Figure 26b. Annual relative abundances in the West-Central basin of spottail shiner by mesh size. Between mesh sizes perspective.

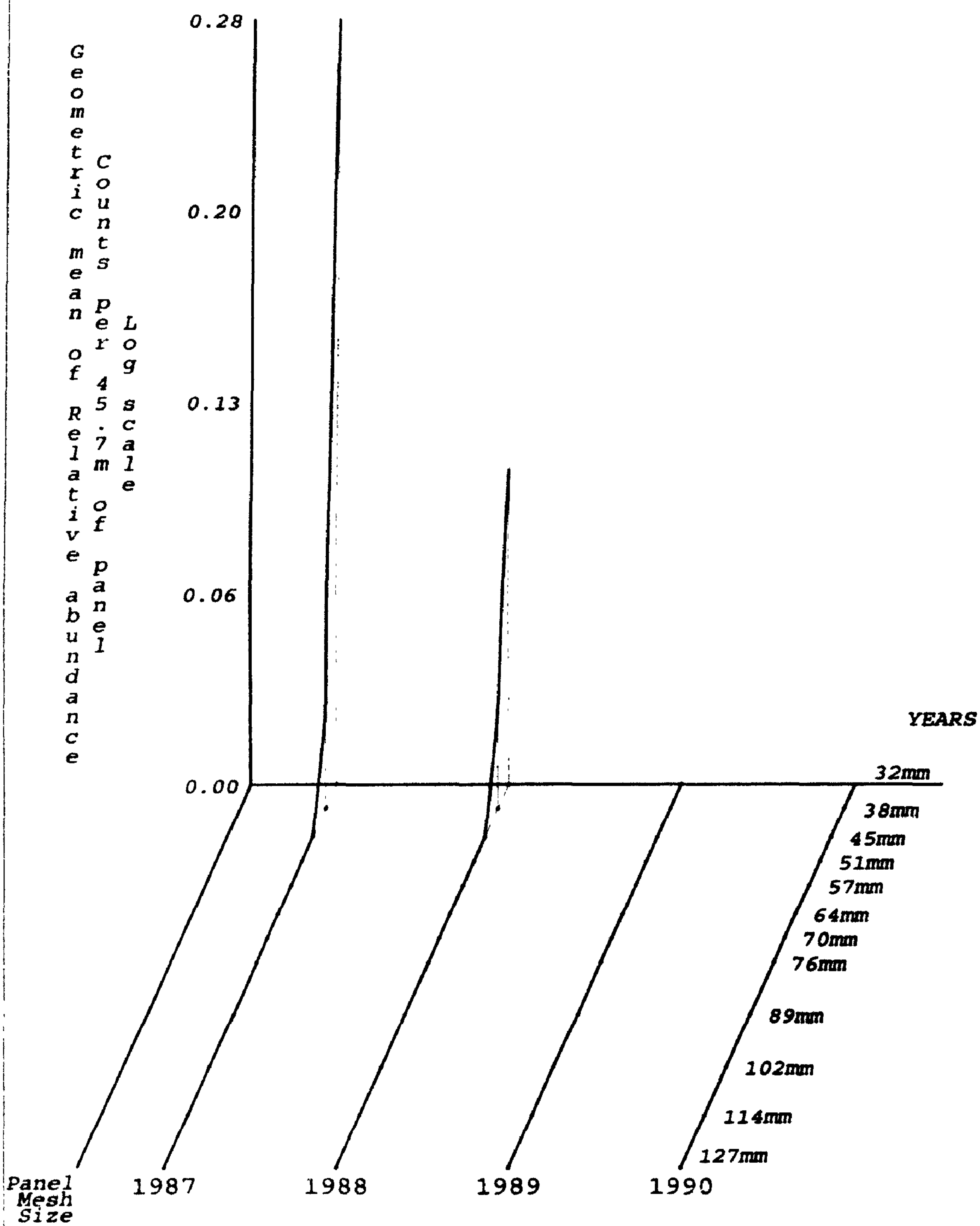


Figure 27a. Annual relative abundances in the West-Central basin of troutperch by mesh size. Between years perspective.

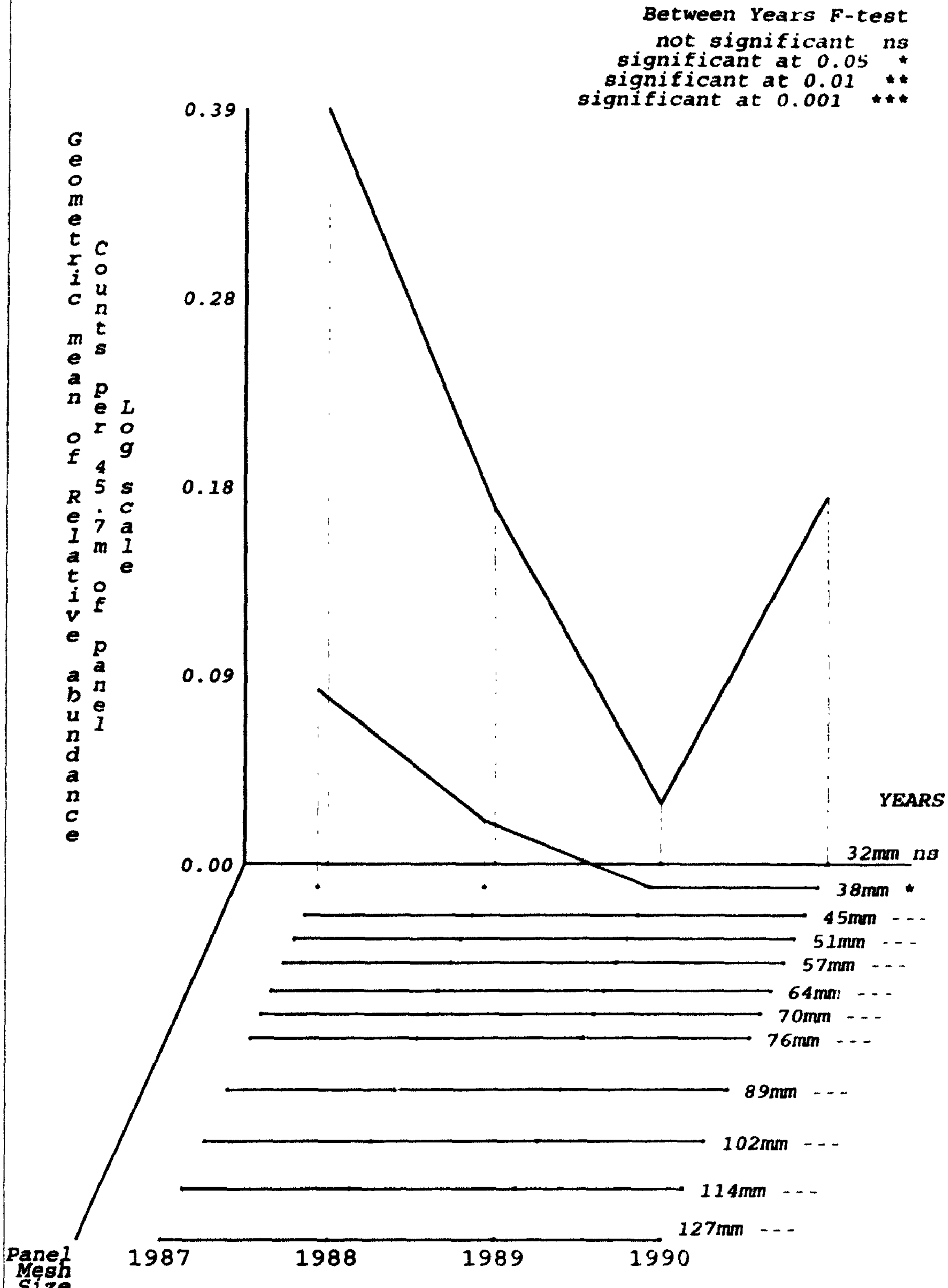


Figure 27b. Annual relative abundances in the West-Central basin of troutperch by mesh size. Between mesh sizes perspective.

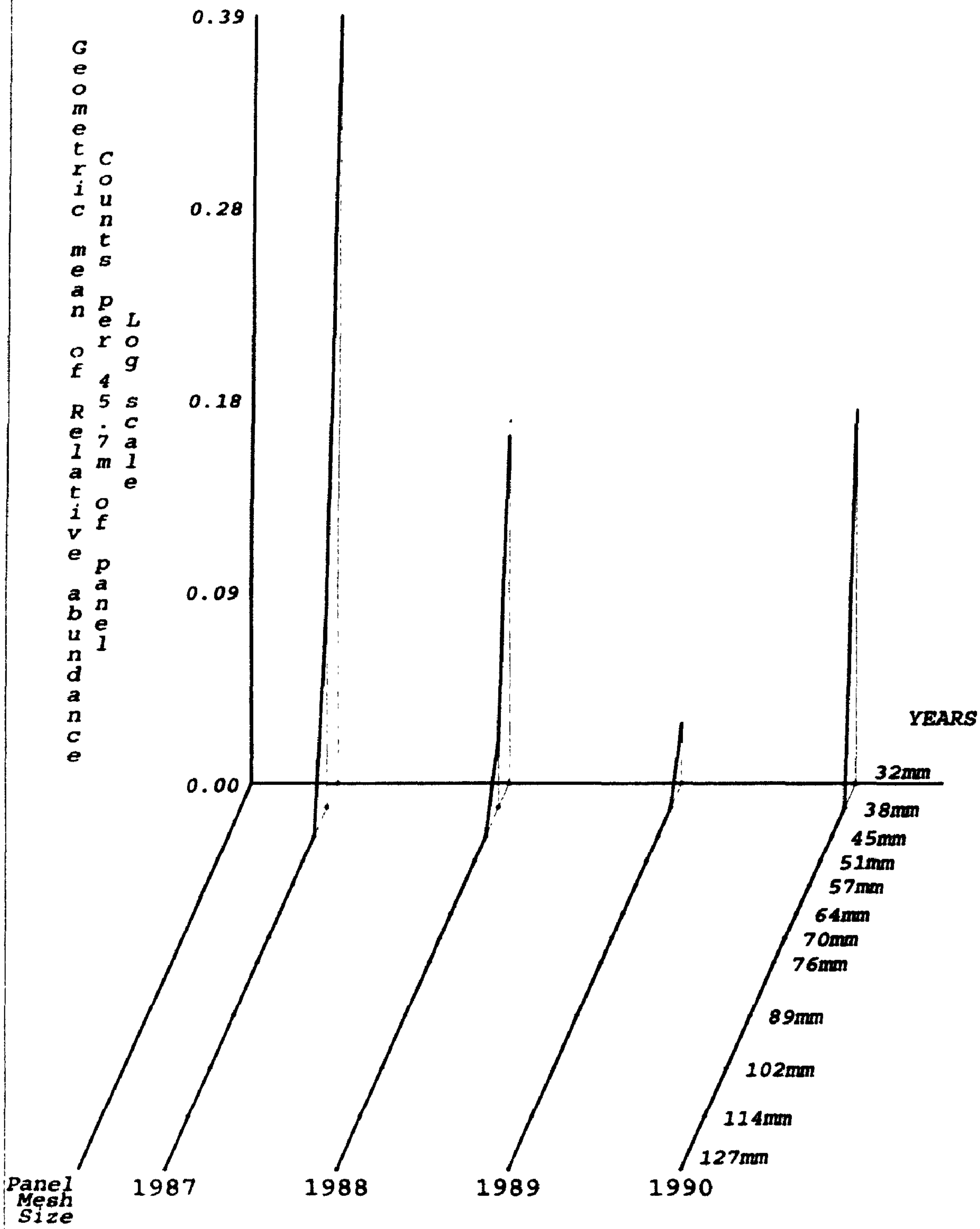


Figure 28a. Annual relative abundances in the West-Central basin of burdot by mesh size. Between years perspective.

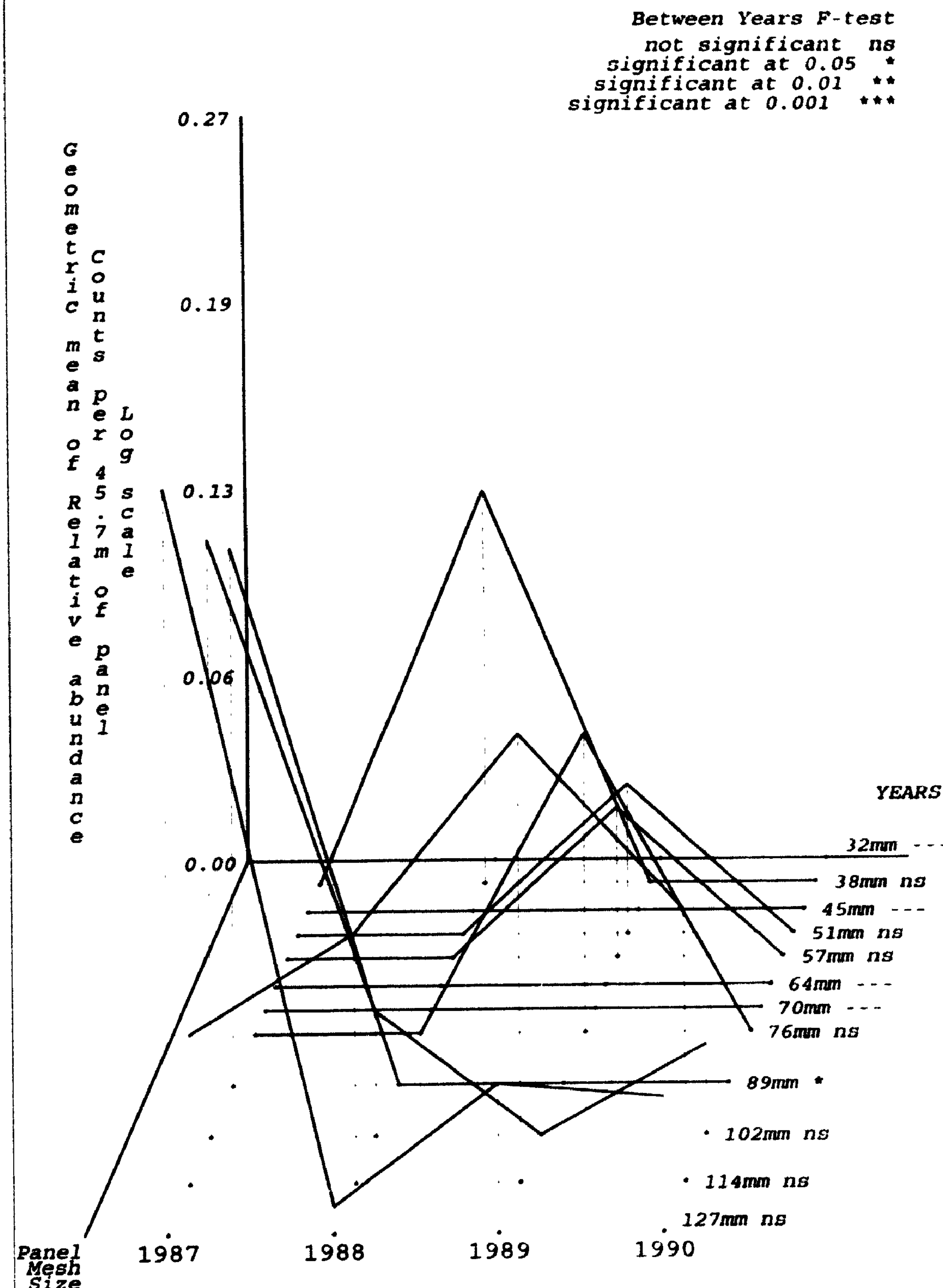


Figure 28b. Annual relative abundances in the West-Central basin of burdot by mesh size. Between mesh sizes perspective.

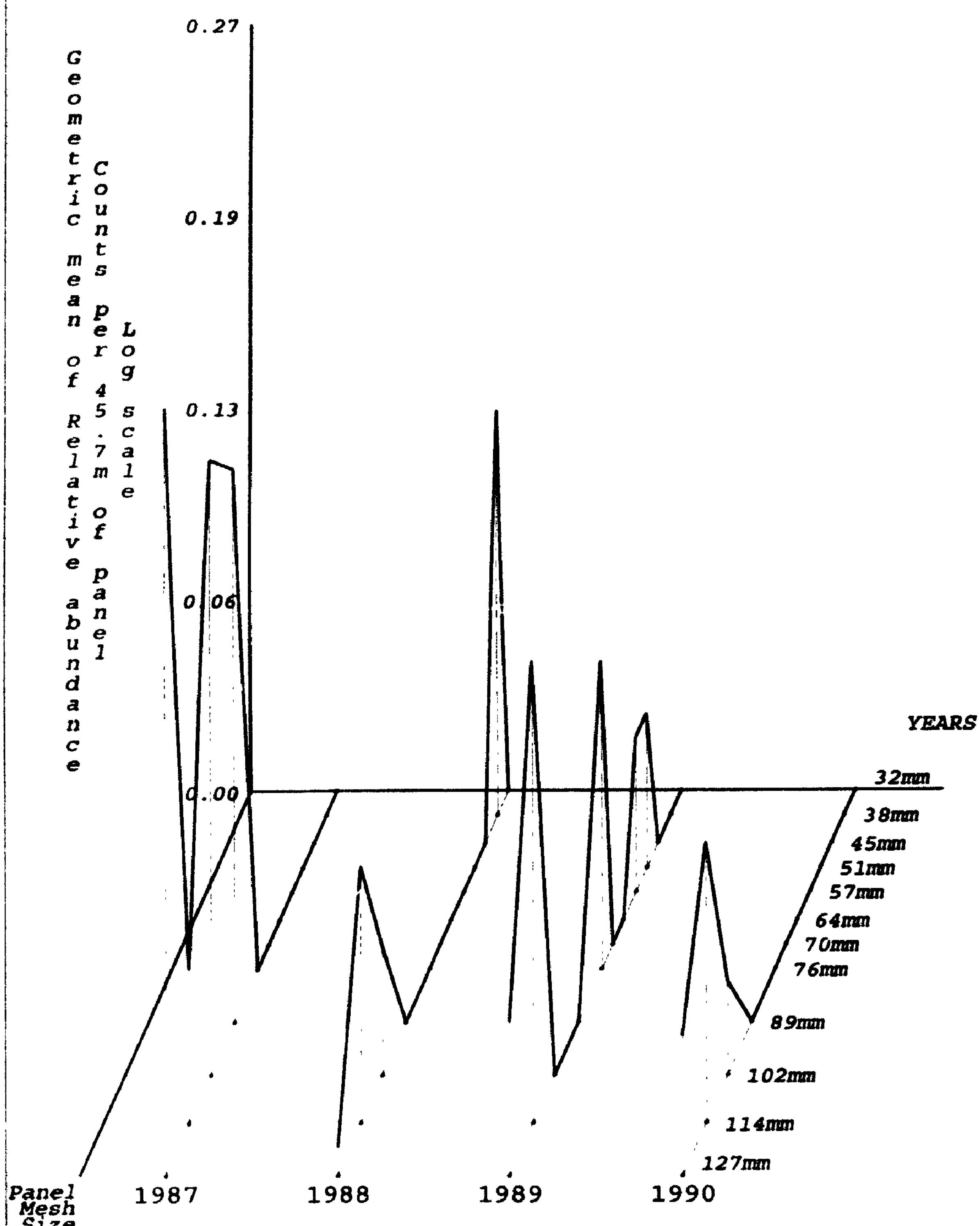
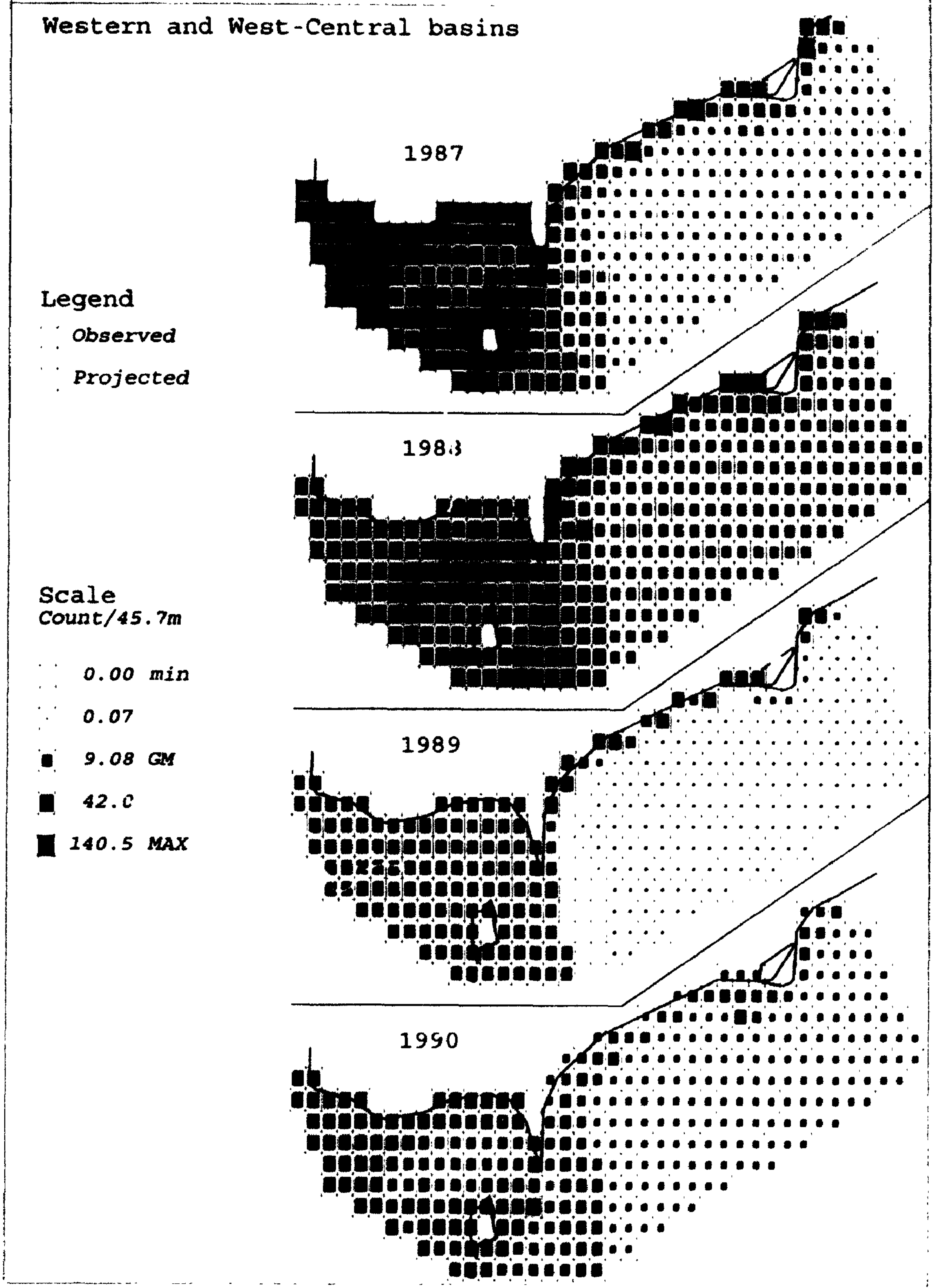


Figure 29. Observed and projected densities of white perch, *Morone americana*, Bar-perche, captured by mesh size panel 45 mm.



4.2 Assessment by principal components

Principal Component Analyses were conducted for the two basins with three types of covariance matrix. The covariances were computed with equation **(77)** that adjusts the overall covariance for the stratification and the occasions. The covariances are then called overall covariances to reflect this level of variation.

The first PCA type conducted is the PCA on the covariance matrix without any standardization. This type is referred in tables as the PCA on COV. The second type is the PCA on the covariance matrix with standardization by the sampling variances. The sampling variance are estimated for all four years for consistency. This type is referred in tables as the PCA on COV/SV. The third PCA type conducted is the PCA on the covariance matrix with standardization by the overall variances which gives the correlation matrix. This type is referred in tables as the PCA on COR.

Tables 16a and 16b report the importance of the eigen values of principal components derived (measured by the Relative variance) by each PCA type for the two basins. F-tests between the average PC scores were conducted and the significance is reported in the tables.

Tables 17a and 17b report the importance of a given species-mesh variable on principal components. Species selected are those of the most important which showed some correlation with one the principal components of these tables. The measure used to evaluate the importance of a variable is the square of the simple correlation between the variable *x* and the PC (Rencher 1992) and expressed in terms of the variance of the original variable.

Then its expression, for the three types of PCA, is given by

$$\%\ \textit{Variance of x expressed on PC} = \frac{\alpha_{PC,x}^{2}\ \lambda_{PC}}{\textit{Diagonal of x}} * 100\ \%\ ;$$

where

$\alpha_{PC,x}$ is the loading coefficient of the eigen vector of *x* for the specified *PC*,

λ_{PC} is the eigen value of the specified *PC* and

Diagonal of x is the variance term on the diagonal of the covariance matrix concerned.

All these terms depend on the type of PCA . Appendix 4, for the Western basin, and appendix 5, for the West-Central basin, report the loading coefficients for the first eight principal components derived from the PCA on COV/SV. Tables 17a and 17b report the computed percent of a given species-mesh variable on each of the first eight principal components of the three PCA's. Only species-mesh variables showing at least 10% or more of their variance in at least one of the first eight Principal Components are presented in these tables.

Table 18a and 18b report, by basin, the statistical tests of change (F-tests and t-tests between consecutive years) conducted on the principal components derived from PCA on the covariance matrix standardized with the sampling variances.

Figures 30.a to 30.h show the principal components by basin of the first eight Principal Components. The basin representations are separate and have their own scale. The observed scores of catch stations sampled and the projected scores based on the stratum-year averages are shown by the size of the dark rectangle. Zero score is the average score and the standard (half the size) for all these figures. The F-tests from table 18a and 18b are reported at the bottom in each figure.

Figures 31.a to 31.h, for the Western basin, and Figures 32.a to 32.h, for the West-Central basin, illustrate the fluctuation of the averages PC scores during time by stratum and for entire basin for the first eight Principal Components.

Table 16a. Relative variance and result (significance) of F-tests between all years in Western basin of each the first sixty eight principal components from three PCA analyses, PCA on COV, PCA on COV/SV and PCA on COR.

PC no	PCA on COV Variance %	sig of F	PCA on COV/SV Variance %	sig of F	PCA on COR Variance %	sig of F
PC1	25.76	***	10.72	***	9.82	***
PC2	17.53	*	7.82	-	7.71	-
PC3	9.13	***	6.12	*	6.38	-
PC4	7.10	***	5.31	***	4.90	-
PC5	5.36	**	4.80	***	4.69	**
PC6	3.90	***	4.19	-	4.33	***
PC7	2.81	-	3.69	*	3.82	**
PC8	2.40	*	3.62	-	3.69	*
PC9	1.85	***	3.32	-	3.62	-
PC10	1.76	-	2.75	*	2.94	-
PC11	1.58	-	2.58	-	2.67	-
PC12	1.44	-	2.44	-	2.51	-
PC13	1.33	-	2.31	-	2.32	-
PC14	1.17	-	2.22	-	2.17	-
PC15	1.02	-	2.08	-	2.11	-
PC16	0.97	-	1.96	-	2.06	**
PC17	0.92	-	1.89	-	1.93	-
PC18	0.87	-	1.82	-	1.75	-
PC19	0.84	-	1.70	-	1.68	*
PC20	0.80	-	1.66	*	1.63	-
PC21	0.76	-	1.51	-	1.55	-
PC22	0.72	-	1.44	-	1.46	-
PC23	0.65	-	1.32	-	1.29	-
PC24	0.59	-	1.27	-	1.29	-
PC25	0.56	-	1.20	-	1.21	-
PC26	0.54	-	1.12	-	1.18	-
PC27	0.50	-	1.09	-	1.12	-
PC28	0.48	-	1.06	-	1.06	-
PC29	0.45	-	0.99	-	1.01	-
PC30	0.45	-	0.96	-	0.99	-
PC31	0.41	-	0.91	-	0.95	-
PC32	0.39	-	0.88	-	0.90	-
PC33	0.35	-	0.86	-	0.88	-
PC34	0.32	-	0.83	-	0.83	-
PC35	0.31	-	0.79	-	0.78	-
PC36	0.28	-	0.78	-	0.74	-
PC37	0.25	-	0.72	-	0.73	-
PC38	0.24	-	0.68	-	0.71	-
PC39	0.21	-	0.65	-	0.66	-

(continued)

(Table 16a continued)

PC40	0.21	-	0.58	-	0.64	-
PC41	0.20	-	0.52	-	0.52	-
PC42	0.19	-	0.52	-	0.50	-
PC43	0.19	-	0.46	-	0.46	-
PC44	0.17	-	0.45	-	0.45	-
PC45	0.17	-	0.41	-	0.42	-
PC46	0.15	-	0.39	-	0.40	-
PC47	0.14	-	0.38	-	0.39	-
PC48	0.14	-	0.35	-	0.35	-
PC49	0.12	-	0.32	-	0.31	-
PC50	0.12	-	0.29	-	0.29	-
PC51	0.11	-	0.27	-	0.27	-
PC52	0.11	-	0.26	-	0.26	-
PC53	0.10	-	0.24	-	0.23	-
PC54	0.09	-	0.23	-	0.23	-
PC55	0.08	-	0.22	-	0.22	-
PC56	0.07	-	0.20	-	0.20	-
PC57	0.07	-	0.19	-	0.19	-
PC58	0.06	-	0.18	-	0.18	-
PC59	0.05	-	0.17	-	0.17	-
PC60	0.05	-	0.17	-	0.16	-
PC61	0.05	-	0.15	**	0.15	*
PC62	0.04	-	0.14	-	0.14	-
PC63	0.04	-	0.13	-	0.13	-
PC64	0.03	-	0.12	-	0.12	-
PC65	0.03	-	0.10	-	0.10	-
PC66	0.03	-	0.09	-	0.09	-
PC67	0.02	-	0.08	-	0.08	-
PC68	0.02	-	0.07	-	0.07	-

Legend
- \- non-significant
- * significant at 0.05
- ** significant at 0.01
- *** significant at 0.001

Table 16b. Relative variance and result (significance) of F-tests between all years in West-Central basin of each the first sixty eight principal components from three PCA analyses, PCA on COV, PCA on COV/SV and PCA on COR.

PC no	PCA on COV		PCA on COV/SV		PCA on COR	
	Variance %	sig of F	Variance %	sig of F	Variance %	sig of F
PC1	37.81	***	22.40	*	15.45	***
PC2	19.93	***	10.56	-	8.45	***
PC3	7.12	***	8.48	**	6.20	**
PC4	4.58	**	5.51	***	4.95	***
PC5	3.64	-	3.64	***	4.21	***
PC6	2.58	*	3.13	***	3.73	-
PC7	2.12	*	2.92	**	3.09	***
PC8	1.87	***	2.52	***	2.94	*
PC9	1.36	-	2.24	-	2.50	-
PC10	1.24	-	2.17	-	2.36	-
PC11	1.18	-	2.02	-	2.12	-
PC12	1.09	-	1.97	*	1.97	-
PC13	1.03	-	1.85	-	1.81	-
PC14	0.95	-	1.77	-	1.74	-
PC15	0.89	-	1.70	-	1.66	-
PC16	0.83	*	1.68	*	1.50	-
PC17	0.77	-	1.56	-	1.42	-
PC18	0.71	-	1.45	-	1.38	-
PC19	0.69	-	1.30	*	1.37	-
PC20	0.66	-	1.27	*	1.30	-
PC21	0.61	-	1.14	-	1.24	-
PC22	0.57	-	1.09	-	1.23	-
PC23	0.54	-	0.98	-	1.17	-
PC24	0.46	-	0.92	-	1.16	-
PC25	0.44	-	0.80	-	1.10	-
PC26	0.43	-	0.77	-	1.06	-
PC27	0.40	-	0.76	-	1.04	-
PC28	0.36	-	0.70	-	1.02	-
PC29	0.33	-	0.67	-	0.93	-
PC30	0.32	-	0.62	-	0.92	-
PC31	0.29	-	0.58	-	0.89	-
PC32	0.27	-	0.56	-	0.87	-
PC33	0.25	-	0.54	-	0.82	-
PC34	0.25	-	0.49	-	0.79	-
PC35	0.24	**	0.47	-	0.78	-
PC36	0.22	-	0.46	-	0.77	-
PC37	0.20	-	0.43	-	0.75	
PC38	0.19	-	0.42	-	0.72	-
PC39	0.17	-	0.41	-	0.69	*

(continued)

(Table 16b continued)

PC40	0.17	-	0.39	-	0.66	-
PC41	0.17	-	0.37	-	0.65	-
PC42	0.15	-	0.35	**	0.61	-
PC43	0.14	-	0.34	-	0.60	-
PC44	0.14	-	0.33	-	0.58	-
PC45	0.13	-	0.32	-	0.55	-
PC46	0.11	-	0.32	-	0.52	-
PC47	0.10	-	0.29	-	0.49	-
PC48	0.09	-	0.27	-	0.48	-
PC49	0.09	-	0.26	-	0.46	-
PC50	0.09	-	0.23	-	0.44	-
PC51	0.08	-	0.22	-	0.43	-
PC52	0.08	-	0.22	-	0.42	-
PC53	0.07	-	0.21	-	0.38	-
PC54	0.06	-	0.21	-	0.33	-
PC55	0.06	-	0.20	-	0.33	-
PC56	0.06	-	0.18	-	0.30	-
PC57	0.05	-	0.18	-	0.29	-
PC58	0.05	-	0.17	-	0.26	-
PC59	0.04	-	0.15	-	0.25	-
PC60	0.04	-	0.14	-	0.24	-
PC61	0.04	-	0.13	-	0.22	-
PC62	0.04	-	0.13	-	0.20	-
PC63	0.03	-	0.12	-	0.20	-
PC64	0.03	-	0.11	-	0.17	-
PC65	0.03	-	0.10	-	0.16	-
PC66	0.03	-	0.10	-	0.16	-
PC67	0.03	-	0.09	-	0.15	-
PC68	0.02	-	0.08	-	0.13	-

Legend
- \- non-significant
- * significant at 0.05
- ** significant at 0.01
- *** significant at 0.001

Table 17a. Percent of the variance of the species-mesh variables in the Western basin expressed on each of the first eight principal components of three PCA analyses, PCA on COV, PCA on COV/SV and PCA on COR. Significance are reported from Table 13.

		32	38	45	51	57	64	70	76	89	102	114	127
WPer		***	***	***	***	ns	***	***	***	ns		ns	
PCA on COV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Wper	PC1	3.62	2.94	0.48	0.07	10.64	11.26	44.52	50.22	59.20	23.79	5.38	0.00
	PC2	58.12	58.98	64.66	80.99	76.81	71.07	26.16	26.65	18.24	37.31	45.30	26.59
	PC3	9.47	11.87	8.36	2.92	0.44	0.18	3.19	3.22	0.86	0.13	2.81	0.08
	PC4	1.25	7.85	4.18	1.40	0.33	0.56	11.72	7.63	1.29	1.33	0.16	1.39
	PC5	0.04	0.52	0.78	0.24	1.68	5.41	2.20	3.45	3.50	0.21	2.72	0.00
	PC6	6.98	5.30	5.02	3.17	0.04	0.94	0.00	0.08	0.01	0.35	1.00	0.47
	PC7	0.03	0.07	1.09	0.00	0.01	0.07	0.34	0.32	0.79	4.89	0.00	0.92
	PC8	5.68	0.08	0.55	2.64	0.14	0.61	0.53	3.26	5.45	0.06	0.87	0.10
PCA on COV/SV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WPer	PC1	27.95	30.48	22.38	19.99	5.16	7.01	7.80	6.36	9.87	0.22	4.40	12.35
	PC2	13.41	16.57	25.15	36.75	55.34	52.87	40.60	48.15	45.75	58.98	39.23	9.80
	PC3	3.62	6.97	4.60	1.66	1.73	4.82	2.98	0.39	1.81	0.65	0.21	1.54
	PC4	11.91	3.60	6.56	10.43	5.30	3.13	6.82	5.18	2.94	0.30	10.32	2.04
	PC5	5.11	3.78	0.70	0.93	0.14	0.13	0.33	1.23	2.48	1.94	1.96	0.82
	PC6	0.00	0.04	0.78	0.68	1.65	2.50	6.13	5.48	5.62	2.33	1.57	5.18
	PC7	0.12	1.37	1.12	0.36	0.20	2.52	2.13	3.46	4.96	3.71	0.30	2.97
	PC8	0.54	0.61	1.82	0.98	1.44	1.04	0.36	0.36	1.04	1.97	0.12	0.03
PCA on COR Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WPer	PC1	26.52	29.82	22.38	20.96	7.76	11.09	5.03	3.18	5.49	1.51	4.81	15.00
	PC2	10.27	12.52	21.18	31.89	51.67	48.01	41.37	48.53	45.70	56.70	36.47	6.38
	PC3	9.20	9.44	9.16	6.81	5.16	8.25	0.01	0.60	5.00	1.33	4.17	3.08
	PC4	2.13	3.28	1.02	0.69	0.15	0.90	0.03	0.00	0.05	0.02	2.12	3.48
	PC5	6.04	1.27	0.11	1.43	0.04	0.25	0.01	0.53	3.06	2.20	1.94	0.17
	PC6	2.48	0.00	1.60	4.47	5.40	4.70	17.96	13.09	8.01	3.88	6.44	6.08
	PC7	3.83	2.16	2.77	2.73	0.06	1.44	0.94	1.68	6.29	5.50	1.68	0.11
	PC8	4.70	2.04	1.57	2.96	1.09	0.94	1.17	0.01	0.03	0.01	1.65	0.09

(continued)

(Table 17a continued)

YPer		***	***	***	***	***	ns	ns	ns	*	ns	ns	ns
PCA on COV													
Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
YPer	PC1	71.00	64.91	55.55	43.05	30.01	11.72	3.09	8.72	11.14	0.06	3.62	0.00
	PC2	1.80	3.62	0.73	0.02	0.56	1.01	0.18	0.10	0.93	0.01	0.39	0.01
	PC3	13.64	7 88	25.88	15.96	4.45	1.07	0.75	0.42	1.65	2.45	0.52	1.47
	PC4	2.02	3.58	9.09	8.83	22.45	27.15	20.21	0.42	0.44	0.37	2.38	1.33
	PC5	0.00	0.15	1.09	12.81	22.71	28.32	15.47	18.32	5.13	0.37	0.12	6.55
	PC6	0.00	0.72	0.19	1.26	0.03	11.75	2.08	2.17	4.23	5.36	2.56	9.64
	PC7	0.17	0.99	0.03	1.06	0.01	0.06	3.54	4.35	0.64	2.98	0.30	1.23
	PC8	1.62	2.41	0.26	0.70	2.39	3.21	6.16	3.08	2.65	0.91	4.41	1.38
PCA on COV/SV													
Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
YPer	PC1	41.69	37.69	27.42	19.39	10.56	7.56	0.28	5.33	13.19	0.85	12.36	3.08
	PC2	22.11	18.58	18.72	23.80	20.23	7.58	7.99	9.16	3.01	0.22	0.01	1.61
	PC3	0.04	0.00	0.05	0.38	0.00	0.90	0.40	5.31	3.53	0.57	0.64	22.55
	PC4	3.29	6.68	6.86	2.87	15.69	5.39	6.23	0.87	0.11	0.17	8.28	9.54
	PC5	8.41	2.70	14.44	7.76	3.27	0.08	0.24	0.00	1.10	0.08	0.29	5.20
	PC6	1.12	2.25	8.79	3.86	4.77	3.25	0.04	0.07	0.10	8.71	0.00	0.92
	PC7	1.23	0.98	0.24	0.03	6.10	15.94	3.27	6.09	1.88	1.35	2.56	1.49
	PC8	2.35	7.95	8.24	8.60	2.37	2.18	0.26	0.01	10.46	9.59	0.53	0.11
PCA on COR													
Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
YPer	PC1	30.54	27.68	18.32	13.76	6.60	6.37	0.07	4.85	13.15	1.01	14.82	3.92
	PC2	24.04	19.15	17.82	23.97	19.08	6.90	6.97	10.22	3.53	0.29	0.02	1.53
	PC3	0.68	1.23	0.32	0.74	1.75	0.01	0.30	4.85	1.77	0.25	5.60	33.83
	PC4	0.66	0.57	0 02	0.06	1.18	2.73	1.86	0.00	0.96	3.02	1.07	1.29
	PC5	5.04	3.37	13.58	4.38	17.17	8.54	2.60	0.69	2.21	0.00	0.00	2.66
	PC6	0.13	0.03	0.31	0.34	3.83	5.13	6.89	0.60	0.04	5.31	0.47	0.30
	PC7	2.21	1.32	1.61	0.16	0.41	4.38	0.09	0.70	1.73	10.12	0.23	0.02
	PC8	9.24	15.47	22.57	21.32	11.84	4.42	1.68	0.09	4.19	12.00	9.79	0.28

(continued)

(Table 17a continued)

FreD		ns	ns	ns	***	**	*	*	*	ns	ns	ns	ns
PCA on COV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
FreD	PC1	4.58	8.28	10.37	61.88	64.41	57.56	48.49	47.85	32.86	10.47	2.49	6.89
	PC2	0.15	2.49	4.38	0.47	0.13	4.17	5.84	4.86	4.63	12.61	14.63	11.46
	PC3	3.06	9.18	15.06	3.44	11.31	19.37	27.23	30.09	42.24	31.01	32.35	26.96
	PC4	0.08	4.54	0.04	4.68	0.27	0.30	5.12	4.32	0.00	0.04	0.00	0.88
	PC5	0.22	6.64	0.28	0.02	1.14	1.44	1.15	1.67	2.33	0.33	0.15	8.93
	PC6	0.10	0.16	0.00	3.33	3.91	0.83	0.06	0.08	0.44	0.09	2.58	0.07
	PC7	0.92	0.02	0.00	4.83	2.98	2.01	0.37	0.59	2.82	15.22	10.59	12.86
	PC8	1.31	0.39	8.78	1.76	0.01	3.22	0.28	0.68	0.02	1.20	11.83	0.41
PCA on COV\SV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
FreD	PC1	3.08	10.43	11.62	33.71	26.60	32.80	38.49	36.54	20.68	18.97	8.76	13.45
	PC2	2.72	1.19	1.73	22.25	31.08	17.88	11.97	10.27	8.61	0.00	0.86	0.41
	PC3	6.86	2.76	0.93	2.20	0.49	0.45	0.26	0.10	1.28	1.33	1.24	0.46
	PC4	0.29	0.17	4.40	2.89	5.91	7.32	0.83	0.23	3.20	3.35	6.89	4.00
	PC5	7.25	11.93	25.64	7.76	9.47	15.89	19.30	20.78	24.28	15.07	15.91	13.39
	PC6	0.68	5.04	0.44	0.12	0.26	0.11	3.42	1.54	3.03	8.15	8.38	11.99
	PC7	0.07	0.29	1.10	0.37	0.02	0.63	1.46	3.10	3.56	1.58	1.94	0.02
	PC8	2.90	1.87	3.23	0.45	0.37	0.06	0.56	1.33	0.11	2.50	4.55	2.17
PCA on COR Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
FreD	PC1	3.35	12.55	10.50	28.03	21.72	28.27	36.90	35.27	19.88	19.75	9.59	14.80
	PC2	2.77	1.85	2.01	25.20	33.93	20.43	15.25	12.91	10.27	0.23	0.39	0.90
	PC3	5.81	1.71	0.44	5.42	4.21	5.66	1.91	1.11	0.16	0.15	0.56	0.62
	PC4	6.90	2.49	22.15	7.34	8.24	14.16	7.55	9.38	15.09	4.72	5.57	2.65
	PC5	0.16	13.78	0.00	0.00	0.03	0.23	4.37	4.16	4.06	2.23	1.02	2.07
	PC6	0.16	2.37	2.28	0.18	2.66	2.24	2.84	0.61	5.58	10.52	15.77	17.98
	PC7	0.35	0.49	5.13	1.32	0.72	0.59	3.26	4.59	7.67	8.41	15.69	3.99
	PC8	3.29	2.76	3.46	1.36	0.55	0.03	1.43	2.54	0.19	2.41	7.51	2.82

(continued)

(Table 17a continued)

Alew		***	***	*	***	*	ns	ns	ns	ns	ns	ns	ns
PCA on COV													
Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Alew	PC1	16.63	14.12	6.58	7.56	0.68	0.08	2.56	5.24	1.63	4.54	4.66	2.56
	PC2	24.90	18.37	16.86	23.64	24.03	0.62	8.33	9.66	0.48	22.30	25.60	8.33
	PC3	2.66	7.00	5.57	7.43	2.49	1.16	0.01	0.81	0.60	0.38	0.59	0.01
	PC4	10.29	18.89	10.21	12.70	19.13	3.92	3.82	3.10	0.88	9.45	10.65	3.82
	PC5	1.72	7.00	8.88	3.25	1.37	4.29	0.08	2.96	0.00	1.38	2.08	0.08
	PC6	16.09	17.82	22.55	27.00	12.19	0.48	0.07	8.78	0.47	1.89	2.94	0.07
	PC7	1.62	3.47	8.92	5.44	11.23	14.62	0.16	0.01	0.92	0.23	0.21	0.16
	PC8	0.03	0.13	0.50	0.01	0.76	0.23	0.03	0.05	3.01	0.52	1.05	0.03
PCA on COV\SV													
Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Alew	PC1	64.69	56.85	43.80	56.07	33.78	1.40	17.11	22.29	1.04	36.92	40.12	17.11
	PC2	3.64	5.74	8.41	11.78	18.58	2.05	1.42	0.57	0.65	4.87	5.91	1.42
	PC3	6.84	5.32	0.46	2.74	8.11	1.28	8.38	9.47	0.01	21.64	24.63	8.38
	PC4	1.59	5.21	8.05	9.03	7.65	1.93	0.28	0.03	1.82	0.31	0.27	0.28
	PC5	1.19	3.77	8.05	3.99	5.04	6.16	0.37	0.08	0.15	0.18	0.09	0.37
	PC6	0.17	1.01	0.03	0.56	0.90	1.48	2.03	0.36	0.01	1.46	1.01	2.03
	PC7	0.09	3.21	2.78	0.78	1.34	28.81	1.84	3.97	0.04	5.20	6.05	1.84
	PC8	0.44	2.05	4.36	0.75	7.15	7.57	0.75	0.34	0.28	0.45	0.28	0.75
PCA on COR													
Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Alew	PC1	64.14	55.14	43.58	57.97	37.49	0.76	18.89	23.21	0.74	41.14	44.81	18.89
	PC2	1.17	2.69	4.68	7.42	12.20	1.24	0.55	0.08	0.66	2.32	2.93	0.55
	PC3	3.88	1.31	0.27	0.03	1.99	0.39	8.27	8.23	0.40	20.40	22.95	8.27
	PC4	5.08	5.80	13.51	7.44	17.89	13.38	0.64	0.03	0.07	1.71	1.96	0.64
	PC5	0.02	0.28	0.40	0.06	0.05	0.10	0.56	0.04	0.48	0.42	0.30	0.56
	PC6	2.90	12.80	7.60	10.50	8.48	8.45	0.55	0.13	0.43	0.07	0.00	0.55
	PC7	0.18	1.17	1.07	0.05	0.30	15.12	0.38	5.74	0.00	1.12	2.76	0.38
	PC8	0.08	0.01	0.07	0.08	1.67	0.01	13.25	1.60	1.08	6.75	3.71	13.25

(continued)

(Table 17a continued)

Wall		*	ns	***	***	***	***	***	*	ns	ns	ns	ns
PCA on COV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Wall	PC1	9.99	1.15	10.79	7.03	7.24	7.14	5.69	8.56	1.01	2.15	0.90	5.43
	PC2	10.21	13.46	12.76	7.72	5.67	8.66	5.75	15.81	2.45	8.12	2.67	1.92
	PC3	1.49	0.03	0.00	6.33	2.56	1.47	12.02	3.93	12.10	1.49	10.05	1.21
	PC4	5.62	0.89	5.23	14.61	32.92	33.64	30.57	17.67	9.47	9.14	1.65	0.86
	PC5	9.48	0.45	8.37	39.55	26.96	31.81	25.91	15.35	6.11	0.84	0.17	0.52
	PC6	7.05	17.66	5.40	1.29	1.38	1.48	0.40	6.75	0.76	14.02	10.16	10.19
	PC7	0.09	0.03	0.53	2.22	0.04	0.04	0.01	0.09	3.12	13.14	18.15	2.37
	PC8	2.46	2.09	2.16	0.04	7.92	1.13	0.94	0.14	16.20	21.18	11.60	6.10
PCA on COV\SV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Wall	PC1	41.96	23.66	36.76	12.47	8.45	7.91	10.00	23.09	2.51	0.80	0.31	0.00
	PC2	1.39	5.18	1.03	0.07	0.13	0.24	0.01	3.02	0.46	12.73	6.45	14.52
	PC3	1.55	0.64	0.34	29.53	28.26	35.06	40.63	27.63	22.38	9.91	8.41	2.55
	PC4	3.46	7.49	2.09	11.67	21.54	23.72	15.48	7.85	5.76	2.10	0.39	0.16
	PC5	0.64	0.04	0.00	1.14	0.47	0.84	0.93	0.78	2.32	6.76	13.67	4.86
	PC6	0.08	1.92	0.61	4.47	3.91	1.40	0.54	1.07	1.50	5.64	4.31	1.39
	PC7	1.78	3.37	3.17	3.76	1.49	9.74	0.17	0.79	1.59	4.87	11.92	4.28
	PC8	2.35	5.40	1.61	3.96	0.00	0.49	0.32	0.04	5.21	0.02	4.54	0.02
PCA on COR Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Wall	PC1	45.25	28.83	35.85	8.62	4.93	4.12	7.33	20.33	2.32	1.22	0.97	0.24
	PC2	0.30	3.58	0.27	0.00	0.23	0.29	0.00	2.79	0.53	14.21	6.62	14.90
	PC3	2.97	3.54	0.80	6.26	3.04	4.81	9.17	6.60	7.04	3.27	3.93	2.17
	PC4	0.00	1.09	0.04	0.02	0.48	1.19	6.51	7.07	8.71	14.32	16.45	5.80
	PC5	0.04	5.04	0.33	6.65	4.40	5.18	6.20	6.32	11.64	3.35	3.09	0.04
	PC6	0.00	0.03	2.78	13.97	19.04	15.48	20.11	4.71	9.22	3.26	2.58	0.24
	PC7	0.01	3.77	5.04	11.24	3.29	15.26	4.64	2.31	0.68	1.50	6.71	0.92
	PC8	8.93	0.18	1.56	0.06	3.03	8.37	0.51	2.67	1.09	0.02	6.62	4.03

(continued)

(Table 17a continued)

WSuc		ns			ns	*	ns	ns	*	ns	ns	ns	ns
PCA on COV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WSuc	PC1	2.48			1.85	5.95	17.18	22.61	27.41	9.84	5.83	0.38	6.11
	PC2	0.99			1.92	3.39	7.35	1.42	7.52	11.66	11.43	6.54	0.79
	PC3	1.17			2.76	0.31	0.68	0.21	0.03	5.13	8.01	12.28	0.00
	PC4	0.60			0.03	4.51	8.80	0.87	3.20	0.65	3.10	0.02	4.45
	PC5	2.95			1.94	0.11	0.14	0.56	0.09	0.11	2.05	1.07	1.13
	PC6	0.05			14.95	5.82	10.48	15.19	3.04	1.59	6.50	13.70	1.79
	PC7	0.07			0.05	14.37	7.59	11.00	14.85	18.67	18.11	14.87	2.01
	PC8	2.63			1.47	2.37	7.78	6.35	1.93	0.48	0.35	0.22	6.59
PCA on COV\SV Sp\mesh		32	38	45	51	57	64	70	76	[illegible]	102	114	127
WSuc	PC1	0.85			8.88	17.56	34.80	26.24	31.91	12.91	12.55	2.19	4.36
	PC2	0.50			0.41	0.01	0.04	1.77	1.48	0.01	0.14	6.38	2.99
	PC3	0.11			10.11	0.08	1.54	0.03	0.00	0.35	0.63	2.53	0.29
	PC4	0.65			10.22	8.49	4.68	0.70	0.75	8.89	4.21	0.04	7.23
	PC5	0.02			0.29	3.95	3.53	1.75	2.22	12.02	14.34	26.66	1.61
	PC6	0.00			0.17	0.02	0.01	3.28	2.30	1.07	1.55	0.56	1.72
	PC7	0.13			0.18	4.47	2.83	2.90	1.77	1.70	5.42	6.18	2.36
	PC8	1.37			0.81	11.56	3.30	1.01	2.62	0.05	0.06	0.09	0.01
PCA on COR Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WSuc	PC1	0.60			10.68	21.45	38.58	26.52	31.81	13.15	13.73	4.67	4.08
	PC2	0.33			0.15	0.20	0.50	2.83	2.33	0.00	0.05	6.45	3.52
	PC3	0.21			17.68	2.66	0.05	0.12	0.20	4.81	0.48	1.10	0.28
	PC4	0.04			0.00	1.33	0.62	3.75	4.30	15.14	16.94	19.18	0.81
	PC5	0.05			1.51	8.12	4.87	0.00	0.09	0.47	0.62	1.33	2.79
	PC6	1.17			0.42	0.42	1.05	1.76	0.80	3.20	2.63	1.51	12.48
	PC7	0.17			3.89	12.72	11.49	8.00	4.76	0.22	6.16	8.65	0.28
	PC8	1.03			2.15	2.19	1.30	0.64	1.15	1.06	0.17	2.22	0.23

(continued)

(Table 17a continued)

		32	38	45	51	57	64	70	76	89	102	114	127
WBas		*	*	**	ns	**	***	***	**	***	*	ns	ns
PCA on COV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WBas	PC1	3.70	4.11	14.14	2.53	2.23	1.14	6.42	3.53	10.19	11.13	1.33	4.18
	PC2	7.02	6.18	12.22	0.72	5.25	8.60	6.44	8.23	2.80	0.34	5.72	0.84
	PC3	0.15	0.42	3.56	2.39	3.90	2.46	5.02	3.22	0.82	0.00	1.94	1.11
	PC4	8.10	18.35	9.75	0.61	11.08	13.31	13.73	16.37	0.94	0.26	0.61	0.33
	PC5	0.71	0.00	0.94	2.14	1.77	3.42	2.43	2.67	2.21	0.01	0.00	0.34
	PC6	0.60	2.03	3.01	3.69	12.04	10.83	14.14	3.93	0.02	2.06	1.20	4.17
	PC7	1.25	0.32	0.35	2.75	3.14	0.69	0.45	0.00	2.11	2.32	1.49	1.43
	PC8	4.19	5.30	3.67	1.33	0.04	0.67	0.90	2.09	2.50	5.45	5.69	3.76
PCA on COV\SV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WBas	PC1	9.99	12.51	39.29	1.64	0.58	0.13	3.04	0.37	2.32	7.18	2.08	2.75
	PC2	1.76	2.06	0.16	4.06	2.81	8.67	9.72	13.19	10.48	6.67	8.04	5.10
	PC3	8.69	14.14	19.19	0.21	2.27	2.04	2.98	4.36	0.86	0.00	2.10	0.04
	PC4	0.91	0.18	0.09	5.38	20.79	37.14	29.01	25.95	4.86	0.05	0.36	5.10
	PC5	3.63	2.67	0.00	12.93	11.01	6.43	15.63	10.09	3.56	0.09	1.32	3.45
	PC6	14.[illegible]4	9.18	0.08	0.42	2.26	1.35	1.24	2.62	0.00	0.48	5.02	0.23
	PC7	1.80	1.82	4.87	0.83	0.05	0.02	0.86	0.52	19.37	7.23	2.02	0.86
	PC8	1.41	0.37	0.00	0.56	0.69	0.74	0.24	0.74	0.00	1.64	5.07	0.01
PCA on COR Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WBas	PC1	10.32	13.46	39.96	2.46	1.06	0.52	4.09	0.67	1.38	5.72	3.42	3.25
	PC2	1.68	1.70	0.05	4.14	2.49	9.75	10.22	14.24	9.84	6.89	7.65	6.72
	PC3	10.03	12.77	15.25	0.25	0.38	2.20	0.52	0.13	1.99	0.00	3.62	0.42
	PC4	9.48	4.80	1.03	6.46	2.84	0.24	3.60	0.01	1.64	0.04	2.73	0.72
	PC5	0.36	0.00	0.04	6.11	6.55	18.23	14.45	21.03	4.56	1.29	1.81	7.33
	PC6	8.20	8.61	0.00	1.84	12.45	9.76	19.40	6.66	5.12	0.20	7.12	3.87
	PC7	0.26	1.90	0.95	3.82	3.22	4.63	1.44	1.27	8.87	4.04	1.73	0.03
	PC8	2.75	0.16	2.24	1.45	6.33	6.18	4.82	8.85	0.11	2.87	0.00	0.71

Table 17b. Percent of the variance of the species-mesh variables in the West-Central basin expressed on each of the first eight principal components of three PCA analyses, PCA on COV, PCA on COV/SV and PCA on COR. Significance from Table 15 are reported.

WPer		**	**	***	***	***	***	***	***	***	ns	ns	ns
PCA on COV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WPer	PC1	45.12	59.49	69.96	81.00	78.36	71.55	53.15	37.07	31.58	32.03	15.80	12.65
	PC2	0.57	0.35	1.37	2.57	12.98	17.31	27.53	47.51	44.19	11.16	6.71	0.17
	PC3	8.11	6.52	1.65	0.10	1.46	1.49	7.83	0.27	0.77	0.00	0.93	0.58
	PC4	11.98	4.92	5.72	2.85	0.07	0.18	0.00	1.26	0.11	9.16	11.30	0.12
	PC5	7.35	3.79	2.71	0.56	0.04	0.08	0.13	0.15	0.01	2.04	0.41	5.42
	PC6	5.36	3.37	0.41	3.92	2.05	0.01	2.28	5.07	2.41	0.00	4.46	1.21
	PC7	3.58	2.05	0.00	2.76	0.53	1.16	0.05	1.89	2.43	4.69	1.48	0.53
	PC8	0.00	1.70	0.10	0.10	0.23	0.13	1.00	0.62	3.62	2.91	0.09	0.04
PCA on COV\SV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WPer	PC1	20.26	28.51	15.17	12.59	10.54	9.62	3.27	3.72	3.24	4.86	6.34	8.44
	PC2	2.33	2.05	1.70	2.92	3.05	2.41	0.19	1.10	0.73	1.92	8.51	1.99
	PC3	12.90	25.12	30.79	28.20	26.82	22.81	13.13	11.14	9.42	9.06	7.69	1.37
	PC4	22.12	19.13	23.34	27.37	27.75	26.96	35.45	22.15	19.54	17.62	3.24	4.35
	PC5	6.11	2.17	1.64	1.36	2.46	2.31	5.17	5.38	5.14	9.81	18.31	1.26
	PC6	0.03	0.02	0.00	0.00	4.28	5.59	9.89	28.63	28.34	6.39	2.25	0.05
	PC7	1.92	0.28	0.77	5.27	8.51	9.98	9.63	8.20	7.90	4.69	0.29	0.24
	PC8	8.25	3.30	2.58	0.24	0.04	0.76	1.02	1.09	0.00	7.36	7.38	0.28
PCA on COR Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WPer	PC1	36.67	50.82	35.55	32.92	28.51	25.43	11.41	10.73	9.07	13.00	14.15	12.62
	PC2	8.37	13.65	23.27	29.49	26.75	24.01	17.59	9.67	7.58	9.63	6.76	0.98
	PC3	0.20	1.25	2.33	1.72	0.99	1.09	3.01	0.10	0.11	0.01	2.68	0.50
	PC4	4.18	4.53	6.36	7.20	20.19	22.67	31.93	48.19	43.36	16.91	6.15	2.23
	PC5	0.04	0.02	0.59	3.40	4.00	5.29	12.44	2.52	1.57	1.06	0.03	1.17
	PC6	7.38	2.69	3.18	1.84	2.04	1.13	1.87	2.92	6.44	19.64	28.94	0.27
	PC7	15.02	4.34	3.02	0.17	0.54	1.00	1.20	0.71	0.75	1.97	0.05	4.11
	PC8	0.12	0.08	0.06	0.32	0.70	0.62	0.65	1.61	3.59	1.55	1.49	0.75

(continued)

(Table 17b continued)

YPer		***	***	***	***	***	***	*	ns	ns	ns	ns	ns
PCA on COV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
YPer	PC1	41.25	44.69	45.81	31.20	18.86	10.57	8.16	6.12	0.84	6.25	0.32	3.59
	PC2	34.64	36.70	42.25	57.53	44.92	33.03	10.77	1.93	0.00	6.05	7.31	4.61
	PC3	4.93	2.75	0.13	0.65	21.60	30.73	37.21	15.70	5.14	3.32	0.20	0.00
	PC4	2.57	0.56	0.00	0.93	0.55	5.44	10.16	4.03	8.42	0.03	0.24	0.24
	PC5	1.14	0.95	0.70	0.38	0.25	0.10	0.07	1.84	2.00	2.10	0.05	0.01
	PC6	5.80	7.01	2.00	0.17	2.58	3.11	0.65	9.51	8.99	0.46	0.00	3.31
	PC7	0.04	0.03	0.06	0.00	0.06	0.03	12.60	5.36	3.36	5.02	4.37	0.05
	PC8	2.76	0.29	1.43	2.51	2.29	1.47	4.23	0.54	1.58	0.52	5.71	0.40
PCA on COV\SV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
YPer	PC1	14.30	12.94	9.71	4.81	0.81	0.14	0.37	0.08	0.24	1.13	0.05	0.02
	PC2	1.99	2.26	2.59	1.52	0.62	1.12	0.08	1.04	1.33	1.50	0.01	0.07
	PC3	8.35	9.62	13.32	9.04	5.21	2.53	0.04	2.72	0.58	0.53	0.66	0.83
	PC4	12.14	12.03	10.31	5.27	2.53	0.48	2.37	0.19	0.10	1.99	0.30	1.71
	PC5	1.88	3.66	4.56	7.72	3.68	3.97	1.65	0.09	0.03	0.77	3.67	0.61
	PC6	36.81	35.88	36.71	44.62	36.88	28.96	10.85	2.22	0.08	9.48	3.06	6.29
	PC7	0.00	0.03	0.02	0.01	1.25	1.28	3.97	0.68	0.62	0.88	1.75	0.13
	PC8	0.58	0.32	0.02	0.03	0.28	3.24	1.20	0.02	0.30	0.00	1.21	0.07
PCA on COR Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
YPer	PC1	28.78	27.60	23.76	13.47	4.32	1.51	1.14	0.95	0.54	3.01	0.28	0.55
	PC2	15.71	18.33	23.09	18.74	15.04	10.98	3.77	5.58	1.27	3.00	1.21	3.51
	PC3	1.50	1.47	1.75	1.67	2.20	0.88	0.80	0.03	0.67	0.02	0.22	0.31
	PC4	13.23	13.25	15.22	23.75	22.76	19.99	6.62	1.36	0.11	3.65	6.64	1.99
	PC5	2.79	3.15	2.78	2.31	7.32	9.17	16.80	2.97	0.36	2.69	0.58	0.27
	PC6	1.84	4.26	6.27	11.95	5.69	12.23	8.11	0.70	1.62	1.31	1.08	2.22
	PC7	12.28	9.46	6.94	4.46	0.01	1.62	5.94	10.33	11.87	5.47	4.14	3.91
	PC8	0.01	0.24	0.05	0.20	0.02	0.31	1.82	0.01	0.29	4.59	0.55	1.12

(continued)

(Table 17b continued)

FreD		ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns
PCA on COV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
FreD	PC1	5.12	4.11	4.02	14.02	26.32	20.53	27.56	34.02	36.42	49.21	42.51	16.52
	PC2	1.52	1.23	2.09	5.80	1.09	1.04	0.59	1.91	0.14	0.57	1.21	0.06
	PC3	3.59	2.52	0.52	25.27	12.81	7.32	16.65	28.53	24.02	10.19	8.45	11.21
	PC4	2.89	8.81	4.18	8.00	18.42	16.02	25.14	7.67	11.96	5.99	2.23	2.91
	PC5	0.70	0.41	3.70	0.65	7.57	15.16	5.06	9.27	2.48	3.58	0.45	0.01
	PC6	1.35	1.15	0.18	3.72	3.54	0.11	0.55	1.75	0.00	1.38	0.90	6.16
	PC7	0.66	0.15	0.32	0.58	1.30	14.26	0.56	0.38	1.07	2.82	0.19	1.35
	PC8	3.14	1.15	0.14	2.27	0.15	0.15	0.50	0.01	0.24	0.07	0.36	8.60
PCA on COV\SV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
FreD	PC1	11.63	1.28	0.15	6.19	7.60	1.35	13.04	12.86	13.70	12.25	14.06	26.04
	PC2	26.13	4.57	0.43	8.80	6.38	0.92	8.95	5.27	7.75	8.50	12.19	9.00
	PC3	0.63	0.04	2.77	17.94	25.07	22.53	9.05	26.93	25.95	23.71	19.87	5.16
	PC4	0.22	0.61	2.42	0.04	1.59	3.22	5.45	3.64	3.01	10.06	11.60	0.12
	PC5	0.32	0.34	4.82	11.46	10.93	16.68	7.88	7.06	2.18	1.69	0.31	0.02
	PC6	2.17	0.65	1.12	1.42	0.01	0.29	0.01	0.51	0.90	0.37	0.72	0.03
	PC7	0.24	0.32	0.00	2.71	0.01	0.07	0.31	0.00	0.08	2.18	1.09	0.07
	PC8	0.49	0.21	0.00	0.07	0.68	2.17	1.34	0.02	1.18	0.01	1.25	0.98
PCA on COR Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
FreD	PC1	13.70	2.79	1.29	14.20	19.05	7.07	24.28	29.38	29.05	30.18	31.83	33.90
	PC2	0.09	1.35	6.29	11.88	18.92	21.04	10.87	20.06	16.20	26.41	20.24	1.70
	PC3	24.72	4.38	0.14	2.49	0.37	1.32	2.44	0.02	0.87	0.16	1.56	3.52
	PC4	0.86	0.10	0.30	0.27	0.41	0.21	1.02	0.07	5.10	1.05	6.38	0.81
	PC5	0.74	0.03	0.10	14.65	7.65	3.44	1.38	9.57	8.01	0.33	0.20	0.70
	PC6	0.82	6.70	5.16	13.43	13.25	17.23	14.34	4.12	5.75	2.87	0.31	2.04
	PC7	0.40	1.75	0.11	1.35	0.00	0.02	0.83	1.69	0.50	0.62	0.19	1.21
	PC8	0.06	1.42	5.64	1.35	3.44	4.82	4.24	3.02	0.72	2.27	0.36	1.70

(continued)

(Table 17b continued)

Alew		*	*	*	*	ns	ns	ns	ns	*	ns	ns	ns
PCA on COV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Alew	PC1	8.64	9.46	11.02	11.55	8.58	4.25	7.16	3.59	6.87	2.55	5.15	4.94
	PC2	0.66	0.59	0.04	0.03	0.05	0.20	0.01	0.49	0.39	0.48	0.03	0.15
	PC3	15.75	11.92	14.37	16.18	9.10	4.68	5.59	5.02	10.16	3.76	4.59	3.14
	PC4	1.18	0.77	0.18	1.03	0.20	0.05	3.07	1.56	1.75	1.75	0.58	5.47
	PC5	12.21	13.18	12.76	16.47	5.12	2.39	4.82	4.95	9.91	2.65	1.73	3.63
	PC6	4.35	6.51	5.26	6.48	7.52	3.97	5.61	2.25	3.99	1.96	5.38	3.50
	PC7	8.10	10.64	5.47	8.83	8.68	6.61	6.72	9.60	12.23	6.87	5.15	3.36
	PC8	11.84	15.94	16.26	8.51	5.27	2.90	3.58	8.25	15.67	4.75	1.23	2.07
PCA on COV\SV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Alew	PC1	62.28	65.41	68.43	60.97	50.68	25.27	48.39	44.81	83.98	25.22	20.49	35.60
	PC2	0.68	0.29	1.14	1.13	23.82	58.54	1.03	39.26	6.77	59.98	46.23	9.09
	PC3	0.37	0.29	0.40	0.02	2.56	4.32	1.08	7.38	5.30	6.33	2.20	0.02
	PC4	0.22	0.25	0.43	0.85	0.09	1.18	0.00	2.96	1.00	2.66	0.24	0.37
	PC5	11.81	5.14	2.51	0.01	0.18	2.46	0.94	1.34	0.67	1.73	2.66	0.12
	PC6	1.35	0.30	1.09	0.45	0.01	0.21	0.00	0.21	0.10	0.27	0.12	0.06
	PC7	4.55	5.28	1.69	5.10	1.27	1.10	5.47	0.37	0.01	0.12	2.45	5.58
	PC8	0.28	2.23	2.48	5.01	3.25	0.28	7.08	0.78	0.14	0.84	3.08	9.37
PCA on COR Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Alew	PC1	53.67	56.77	61.79	58.60	51.12	27.41	45.84	38.76	67.93	24.06	25.01	31.52
	PC2	8.39	8.50	7.87	6.26	2.43	0.08	5.96	3.71	14.26	0.47	0.01	8.56
	PC3	1.05	0.43	1.49	1.26	26.07	59.11	2.27	43.36	10.00	61.32	46.10	5.82
	PC4	0.17	0.30	0.00	0.00	1.60	2.07	1.29	2.18	1.22	1.94	1.79	0.39
	PC5	0.15	0.03	0.06	0.03	0.17	0.62	0.04	1.00	0.35	0.97	0.29	0.04
	PC6	2.56	1.95	0.17	2.50	6.68	3.53	15.61	0.00	0.47	0.00	10.83	15.46
	PC7	0.22	0.29	0.00	1.19	0.56	0.82	0.78	1.47	0.94	1.01	0.52	0.37
	PC8	2.26	1.11	0.66	0.01	0.46	1.20	2.67	2.86	0.00	4.16	0.02	7.18

(continued)

(Table 17b continued)

Wall		ns	ns	ns	*	*	**	***	***	***	***	***	ns
PCA on COV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Wall	PC1	0.00	2.47	0.13	17.91	6.63	13.17	8.62	14.80	3.16	1.71	2.97	0.44
	PC2	0.06	0.16	0.50	2.35	0.55	5.88	0.19	1.97	0.24	2.93	0.07	0.01
	PC3	0.92	0.00	0.60	4.99	1.34	4.87	9.23	1.11	12.02	11.97	16.01	5.70
	PC4	0.03	3.70	1.36	0.01	0.14	0.09	0.43	1.50	0.09	2.29	0.88	2.56
	PC5	4.59	0.07	0.21	1.27	0.00	1.54	0.04	2.88	0.11	1.54	3.73	5.33
	PC6	0.00	0.01	0.57	3.83	1.81	0.17	0.43	6.26	3.09	0.27	0.88	0.77
	PC7	1.62	0.17	0.79	0.89	24.36	12.41	22.02	14.72	10.78	2.28	0.65	0.03
	PC8	2.40	0.75	0.59	15.83	7.09	11.26	15.43	9.94	16.80	4.97	11.41	5.94
PCA on COV\SV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Wall	PC1	8.71	0.14	0.05	45.10	0.03	0.24	0.01	0.06	0.13	0.26	0.06	0.07
	PC2	5.57	0.12	0.23	2.24	0.01	0.23	0.02	0.12	0.00	0.00	0.03	0.04
	PC3	0.03	[illegible]	0.19	6.46	1.52	6.57	1.63	4.64	0.32	0.12	0.34	0.13
	PC4	0.08	[illegible]	0.13	2.84	4.50	4.83	5.95	10.50	3.31	2.33	2.50	0.95
	PC5	0.89	[illegible]	0.14	0.03	0.03	1.13	0.12	0.14	0.03	0.04	0.08	0.12
	PC6	0.51	[illegible]	0.09	3.24	6.12	15.19	4.31	10.59	3.46	0.72	1.59	1.80
	PC7	6.53	3.01	[illegible]	0.85	2.18	3.91	4.46	2.66	4.00	2.49	7.13	0.62
	PC8	1.22	[illegible]	0.94	0.43	10.61	8.04	6.65	2.36	7.36	6.28	2.28	6.25
PCA on COR Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Wall	PC1	5.66	0.82	0.05	48.78	0.89	2.99	0.41	1.95	0.01	0.09	0.07	0.01
	PC2	6.56	2.44	0.11	0.09	5.88	15.49	7.41	16.36	4.71	2.10	4.63	2.02
	PC3	4.68	0.10	0.76	0.02	2.31	3.44	2.30	4.30	1.65	0.47	0.59	1.02
	PC4	0.82	0.54	0.70	2.27	0.03	3.21	0.09	0.38	0.01	2.93	0.04	0.28
	PC5	0.27	1.27	0.01	0.57	15.12	12.20	20.05	17.14	25.76	13.30	11.99	7.05
	PC6	0.04	5.10	0.82	1.80	6.00	2.73	1.56	0.45	2.93	0.84	0.03	1.28
	PC7	0.18	0.00	3.98	4.82	0.89	5.07	5.45	0.48	15.90	22.48	21.81	9.94
	PC8	3.73	2.51	20.69	6.11	10.07	2.69	3.87	2.74	1.48	0.07	1.40	0.18

(continued)

(Table 17b continued)

RaSm		ns	*	**	**	**	**	**	*	*	*	ns	ns
PCA on COV													
Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
RaSm	PC1	1.97	0.76	9.27	11.61	10.13	3.98	3.25	3.91	3.33	1.54	3.25	0.00
	PC2	0.48	0.58	1.04	7.90	5.52	16.33	13.00	8.46	11.28	17.[illegible]	1.12	7.32
	PC3	0.16	1.69	6.10	0.75	0.49	0.11	1.55	0.05	0.47	0.16	0.17	0.51
	PC4	15.89	5.75	3.43	16.42	26.67	19.94	20.44	26.77	20.51	10.57	7.95	5.57
	PC5	19.44	19.28	16.43	34.30	35.81	18.34	29.37	28.58	16.42	2.53	4.34	10.64
	PC6	2.08	2.56	5.04	0.05	1.74	0.10	0.59	1.59	0.10	0.71	13.07	0.09
	PC7	0.33	0.51	3.38	1.54	0.34	2.70	0.10	5.51	5.18	2.99	0.11	0.15
	PC8	1.72	4.18	1.38	0.19	1.65	0.00	2.10	0.52	2.08	7.73	0.36	0.43
PCA on COV\SV													
Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
RaSm	PC1	0.01	0.06	0.02	0.02	0.08	0.05	0.00	0.00	0.05	0.03	0.49	0.07
	PC2	0.00	0.00	0.04	0.56	0.30	0.20	0.02	0.07	0.01	0.10	0.46	0.00
	PC3	3.14	3.63	6.10	13.22	11.58	5.86	3.94	5.57	2.30	2.13	7.34	0.05
	PC4	0.08	0.07	2.13	0.09	0.24	0.00	0.77	0.00	0.18	0.04	0.30	0.00
	PC5	0.01	0.04	1.55	0.00	0.20	0.67	0.04	0.10	0.03	0.05	0.00	0.33
	PC6	3.76	5.89	0.83	19.59	17.14	24.53	28.94	19.55	21.56	20.35	2.47	11.19
	PC7	2.15	1.39	9.25	11.16	8.08	2.65	1.17	2.32	1.26	0.04	2.01	0.00
	PC8	2.72	0.00	0.30	7.87	7.17	10.96	1.93	7.84	4.62	7.31	13.46	1.46
PCA on COR													
Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
RaSm	PC1	0.18	0.07	0.52	2.26	2.40	1.60	0.86	0.85	0.24	0.81	2.51	0.00
	PC2	7.40	6.17	12.79	26.46	22.31	12.73	13.76	13.78	10.24	5.33	6.21	1.84
	PC3	2.07	2.11	3.14	3.02	3.96	2.25	4.07	3.29	2.79	0.89	0.15	0.53
	PC4	6.05	4.04	0.02	22.80	18.48	32.94	27.40	27.41	27.94	27.35	5.04	16.90
	PC5	0.11	0.52	2.46	0.18	0.01	1.11	0.00	0.38	0.00	0.36	3.56	0.96
	PC6	12.99	1.70	4.88	15.79	20.65	13.06	7.40	18.88	8.52	5.60	14.14	3.10
	PC7	1.59	0.47	6.58	2.23	2.89	0.12	1.82	0.11	1.79	3.36	2.74	3.73
	PC8	0.07	0.80	0.00	1.75	0.05	1.74	0.67	0.17	0.17	0.38	3.16	0.07

(continued)

(Table 17b continued)

WBas		ns	ns	ns	ns	*	**	ns	ns	ns	ns	ns	
PCA on COV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WBas	PC1	2.81	1.41	6.94	7.39	7.29	7.13	7.39	11.76	2.17	0.55	0.25	
	PC2	3.08	1.58	0.04	0.85	0.59	0.49	0.10	1.84	7.59	4.46	1.15	
	PC3	2.64	0.74	8.17	6.13	0.00	1.45	0.23	0.14	2.08	0.00	0.42	
	PC4	0.03	0.03	0.01	0.80	1.26	0.30	0.60	1.49	0.01	0.50	0.83	
	PC5	8.68	11.00	7.29	14.19	10.11	0.01	7.40	5.44	0.14	0.70	0.05	
	PC6	2.76	0.23	0.45	2.31	0.02	0.43	1.31	0.04	0.23	0.01	0.67	
	PC7	3.42	3.48	10.72	9.40	0.05	2.40	6.02	0.51	7.93	6.52	3.91	
	PC8	3.72	5.47	13.66	16.80	2.04	3.64	4.11	0.02	0.45	0.44	0.70	
PCA on COV\SV Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WBas	PC1	24.06	37.58	72.87	81.22	13.16	4.41	5.08	8.40	7.26	0.01	0.00	
	PC2	6.44	21.09	2.71	0.01	5.61	1.14	1.35	2.31	0.26	0.04	0.02	
	PC3	0.02	1.29	0.48	2.59	3.09	11.15	3.51	6.14	0.16	0.36	0.12	
	PC4	0.18	0.34	0.05	0.15	4.61	2.64	5.86	9.48	0.55	1.33	0.59	
	PC5	4.94	0.63	0.35	0.31	19.33	11.85	7.09	23.22	1.72	1.26	0.61	
	PC6	0.41	0.35	0.34	0.01	0.47	4.38	1.29	0.02	8.75	5.68	2.16	
	PC7	2.54	0.40	1.07	1.38	13.80	15.70	2.02	11.01	0.50	0.89	0.46	
	PC8	2.52	0.11	0.44	0.12	5.82	12.15	12.15	8.89	0.06	0.26	0.10	
PCA on COR Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WBas	PC1	19.80	24.68	57.81	64.29	13.93	7.64	7.55	11.78	7.44	0.16	0.04	
	PC2	8.32	23.15	15.64	16.86	0.66	2.57	0.35	0.22	0.34	0.37	0.17	
	PC3	6.34	15.40	1.90	0.31	11.54	8.45	5.64	7.96	0.28	0.07	0.07	
	PC4	1.37	1.22	0.07	0.85	4.93	0.71	4.45	8.66	7.53	7.88	3.94	
	PC5	0.23	0.03	0.06	0.48	2.53	0.02	4.93	0.82	0.12	0.00	0.07	
	PC6	2.68	0.50	0.00	0.74	0.03	0.26	1.28	0.54	2.68	1.40	0.33	
	PC7	1.58	0.01	0.09	0.08	4.38	4.03	1.39	6.70	0.19	0.25	0.37	
	PC8	4.16	2.32	0.52	0.07	37.04	29.89	22.42	25.91	0.10	0.91	0.41	

Table 18a. Results (significance) of F-tests between all years and of t-tests (one-tailed) by pairs of successive years on all Principal Components derived in the Western basin from a PCA with covariance standardized with the sampling variance of the means.

PC	F	sig of F	t 87/88	sig of t	t 88/89	sig of t	t 89/90	sig of t
PC1	24.448	***	-3.53	**	-4.36	***	-0.18	-
PC2	0.797	-	-0.50	-	0.12	-	1.44	-
PC3	4.333	*	2.59	*	-5.80	***	2.24	*
PC4	20.227	***	5.22	***	-7.37	***	-2.15	*
PC5	7.384	***	-1.17	-	1.60	-	3.12	**
PC6	2.463	-	-1.84	-	2.74	*	-1.62	-
PC7	3.739	*	0.31	-	5.41	***	-2.24	*
PC8	0.124	-	0.49	-	-1.47	-	0.01	-
PC9	1.168	-	-1.26	-	0.15	-	-0.64	-
PC10	3.079	*	-0.69	-	4.65	***	-2.62	*
PC11	0.371	-	0.98	-	-1.05	-	0.35	-
PC12	1.871	-	0.75	-	2.49	*	-0.63	-
PC13	2.054	-	-0.41	-	2.79	*	-1.37	-
PC14	1.487	-	-2.10	-	0.08	-	-0.10	-
PC15	0.507	-	-0.40	-	0.63	-	-1.66	-
PC16	0.252	-	0.27	-	-0.48	-	-0.26	-
PC17	2.500	-	-0.74	-	-0.12	-	2.29	*
PC18	0.291	-	-0.66	-	0.01	-	-0.41	-
PC19	0.960	-	-1.40	-	0.93	-	-0.91	-
PC20	3.849	*	0.81	-	-2.92	*	3.14	**
PC21	0.078	-	0.14	-	-0.37	-	0.41	-
PC22	0.661	-	-0.38	-	0.98	-	0.53	-
PC23	1.201	-	-1.55	-	1.11	-	-0.21	-
PC24	1.055	-	-0.71	-	-1.32	-	1.20	-
PC25	0.615	-	-1.02	-	-0.22	-	0.92	-
PC26	0.753	-	0.01	-	-1.16	-	1.48	-
PC27	0.346	-	-0.51	-	0.31	-	0.78	-
PC28	1.243	-	1.75	-	-0.39	-	-0.40	-
PC29	0.196	-	-0.54	-	-0.21	-	0.50	-
PC30	0.903	-	-0.82	-	-0.90	-	1.14	-
PC31	0.426	-	1.05	-	-0.70	-	0.02	-
PC32	0.093	-	0.54	-	-0.04	-	-0.09	-
PC33	0.226	-	-0.69	-	0.20	-	0.38	-
PC34	0.184	-	-0.17	-	-0.47	-	0.69	-
PC35	0.257	-	-0.08	-	0.59	-	-0.80	-
PC36	0.197	-	-0.07	-	-0.53	-	0.74	-
PC37	0.040	-	-0.27	-	0.10	-	0.09	-
PC38	0.302	-	0.14	-	-0.64	-	-0.48	-
PC39	1.166	-	0.62	-	-1.93	-	1.61	-
PC40	0.200	-	0.42	-	0.07	-	0.23	-
PC41	0.394	-	-0.65	-	-0.16	-	0.87	-
PC42	1.313	-	0.38	-	-1.87	-	1.69	-

(continued)

(Table 18a continued)

PC	F	sig of F	t 87/88	sig of t	t 88/89	sig of t	t 89/90	sig of t
PC43	0.858	-	1.00	-	-1.40	-	1.12	-
PC44	0.316	-	0.55	-	-0.25	-	0.76	-
PC45	0.408	-	-0.38	-	-0.59	-	0.46	-
PC46	0.338	-	-0.58	-	-0.18	-	0.83	-
PC47	0.192	-	0.31	-	-0.28	-	0.70	-
PC48	0.893	-	1.01	-	-1.23	-	1.16	-
PC49	0.019	-	-0.16	-	0.06	-	0.16	-
PC50	0.426	-	0.35	-	-0.34	-	0.99	-
PC51	0.259	-	0.65	-	-0.50	-	0.33	-
PC52	0.130	-	-0.22	-	-0.21	-	-0.10	-
PC53	0.486	-	0.73	-	-0.89	-	0.92	-
PC54	0.432	-	-0.25	-	0.06	-	0.95	-
PC55	0.048	-	0.37	-	-0.30	-	0.04	-
PC56	0.191	-	-0.79	-	0.19	-	0.33	-
PC57	0.258	-	0.24	-	-0.83	-	0.43	-
PC58	0.629	-	0.96	-	-1.07	-	0.03	-
PC59	0.237	-	0.09	-	-0.55	-	1.06	-
PC60	1.017	-	1.19	-	-0.32	-	-1.27	-
PC61	4.679	**	-0.46	-	-2.01	-	3.14	**
PC62	0.005	-	0.06	-	-0.10	-	0.12	-
PC63	0.512	-	-0.86	-	0.84	-	-0.88	-
PC64	0.074	-	0.02	-	-0.36	-	0.11	-
PC65	0.033	-	-0.37	-	0.11	-	0.13	-
PC66	0.090	-	0.07	-	0.10	-	-0.39	-
PC67	0.501	-	0.70	-	-0.88	-	0.82	-
PC68	0.002	-	0.05	-	-0.06	-	0.05	-
PC69	0.156	-	0.22	-	0.26	-	-0.59	-
PC70	0.433	-	-0.36	-	-0.42	-	0.95	-
PC71	0.083	-	-0.10	-	-0.22	-	0.38	-
PC72	0.259	-	-0.41	-	-0.22	-	-0.09	-
PC73	0.119	-	-0.55	-	-0.12	-	0.41	-

Legend
- \- non-significant
- * significant at 0.05
- ** significant at 0.01
- *** significant at 0.001

Table 18b. Results (significance) of F-tests between all years and of t-tests (one-tailed) by pairs of successive years on all Principal Components derived in the West-Central basin from a PCA with covariance standardized with the sampling variance of the means.

PC	F	sig of F	t 87/88	sig of t	t 88/89	sig of t	t 89/90	sig of t
PC1	6.677	*	-1.59	-	-6.29	***	2.83	**
PC2	0.493	-	-0.29	-	-2.95	**	2.34	*
PC3	7.386	**	2.01	-	-5.73	***	1.74	-
PC4	17.152	***	5.40	***	-6.78	***	3.37	**
PC5	6.896	***	2.79	**	-2.24	*	3.72	**
PC6	41.490	***	1.11	-	-8.59	***	-3.31	**
PC7	6.617	**	2.64	*	-2.59	*	5.11	***
PC8	10.049	***	3.62	**	-0.43	-	-1.49	-
PC9	1.629	-	-0.07	-	1.50	-	-2.58	*
PC10	2.324	-	1.89	-	-2.46	*	1.13	-
PC11	0.901	-	1.03	-	0.39	-	-1.15	-
PC12	6.117	*	2.92	*	-3.14	**	3.58	**
PC13	1.301	-	1.54	-	-1.12	-	0.19	-
PC14	1.856	-	-0.41	-	-2.94	*	0.94	-
PC15	2.442	-	1.14	-	-1.15	-	2.12	-
PC16	3.379	*	0.05	-	-0.14	-	3.01	**
PC17	2.585	-	-1.93	-	2.15	-	-1.87	-
PC18	0.635	-	-0.44	-	-1.16	-	1.07	-
PC19	3.048	*	0.16	-	0.15	-	3.43	**
PC20	3.561	*	2.58	*	-1.30	-	0.25	-
PC21	0.634	-	0.48	-	-1.20	-	1.73	-
PC22	0.974	-	-0.66	-	-0.49	-	-0.25	-
PC23	1.162	-	0.65	-	-0.94	-	2.28	*
PC24	0.348	-	-0.28	-	1.05	-	-0.80	-
PC25	0.742	-	-0.30	-	-0.24	-	-1.00	-
PC26	0.309	-	0.60	-	-0.74	-	0.01	-
PC27	0.475	-	-0.32	-	-0.73	-	0.33	-
PC28	0.334	-	-0.19	-	-0.50	-	-0.16	-
PC29	0.998	-	0.07	-	0.44	-	-1.82	-
PC30	0.811	-	1.24	-	-0.31	-	-0.45	-
PC31	0.794	-	-0.23	-	1.18	-	-0.17	-
PC32	0.374	-	-0.34	-	-0.59	-	1.92	-
PC33	0.940	-	-0.50	-	-0.86	-	1.51	-
PC34	0.763	-	-1.10	-	0.17	-	-0.16	-
PC35	1.668	-	-1.40	-	-0.32	-	2.25	*
PC36	0.783	-	-0.06	-	1.74	-	-1.26	-
PC37	1.514	-	1.71	-	-1.96	-	0.39	-
PC38	0.216	-	-0.34	-	0.57	-	-0.67	-
PC39	0.472	-	1.03	-	-0.90	-	-0.11	-
PC40	2.461	-	1.32	-	0.87	-	-2.17	*
PC41	1.411	-	-1.44	-	1.95	-	-0.29	-
PC42	4.589	**	-2.16	*	-0.02	-	2.98	**

(continued)

(table 18b continued)

PC	F	sig of F	t 87/88	sig of t	t 88/89	sig of t	t 89/90	sig of t
PC43	0.231	-	0.40	-	-0.79	-	0.70	-
PC44	0.637	-	-0.83	-	0.73	-	-1.24	-
PC45	1.454	-	0.64	-	0.42	-	-2.58	*
PC46	0.376	-	0.08	-	-0.03	-	0.90	-
PC47	0.071	-	0.27	-	-0.29	-	0.38	-
PC48	0.351	-	-0.42	-	0.48	-	-1.04	-
PC49	0.048	-	-0.20	-	0.27	-	-0.29	-
PC50	0.365	-	-0.34	-	0.40	-	-0.86	-
PC51	0.933	-	-0.89	-	-0.22	-	1.17	-
PC52	0.356	-	0.06	-	0.86	-	-0.81	-
PC53	0.915	-	0.34	-	0.87	-	-1.56	-
PC54	0.249	-	0.47	-	-0.57	-	0.67	-
PC55	0.109	-	0.44	-	0.16	-	-0.28	-
PC56	0.831	-	0.04	-	0.55	-	0.77	-
PC57	0.085	-	0.00	-	-0.09	-	0.41	-
PC58	0.212	-	-0.10	-	0.60	-	-0.65	-
PC59	0.544	-	-0.94	-	-0.49	-	0.52	-
PC60	0.008	-	0.12	-	-0.05	-	0.08	-
PC61	0.139	-	0.02	-	0.19	-	0.42	-
PC62	1.029	-	-1.68	-	0.82	-	0.02	-
PC63	0.124	-	0.33	-	0.02	-	0.28	-
PC64	0.333	-	0.37	-	-0.22	-	0.72	-
PC65	0.898	-	0.68	-	-1.57	-	0.53	-
PC66	0.392	-	-0.20	-	-0.78	-	-0.17	-
PC67	0.735	-	0.86	-	0.65	-	-0.84	-
PC68	0.933	-	-0.71	-	-1.11	-	1.09	-
PC69	0.978	-	0.53	-	0.36	-	-1.33	-
PC70	0.509	-	-0.19	-	1.20	-	-0.57	-
PC71	0.977	-	-0.30	-	1.47	-	-1.59	-
PC72	0.335	-	1.35	-	-0.58	-	-0.04	-
PC73	0.451	-	-0.40	-	-0.76	-	0.63	-
PC74	0.550	-	1.49	-	-0.86	-	0.20	-
PC75	0.311	-	-0.51	-	0.65	-	0.47	-
PC76	0.641	-	-0.16	-	0.89	-	-1.34	-
PC77	0.212	-	-0.83	-	-0.13	-	0.44	-
PC78	0.295	-	-0.42	-	-0.46	-	0.06	-
PC79	0.438	-	-0.46	-	-0.35	-	1.38	-
PC80	0.755	-	1.29	-	-0.88	-	0.94	-
PC81	0.370	-	-0.68	-	1.37	-	-0.28	-
PC82	2.771	-	-1.59	-	-1.01	-	2.37	*
PC83	0.518	-	0.73	-	-1.39	-	0.51	-
PC84	0.163	-	-0.53	-	0.76	-	-0.32	-
PC85	0.826	-	1.19	-	0.11	-	-0.04	-
PC86	0.209	-	-0.76	-	-0.05	-	0.38	-
PC87	0.287	-	-0.16	-	-0.78	-	0.37	-

(continued)

(table 18b continued)

PC	F	sig of F	t 87/88	sig of t	t 88/89	sig of t	t 89/90	sig of t
PC88	1.853	-	0.12	-	-2.71	*	2.81	**
PC89	0.225	-	-0.71	-	0.54	-	-0.56	-
PC90	0.961	-	-1.51	-	0.42	-	0.38	-
PC91	0.672	-	0.87	-	-1.50	-	0.96	-
PC92	0.302	-	-0.41	-	0.71	-	-0.64	-
PC93	0.065	-	-0.28	-	-0.06	-	0.35	-
PC94	0.396	-	0.76	-	0.31	-	-0.78	-
PC95	0.070	-	-0.82	-	0.12	-	0.11	-
PC96	1.497	-	-0.14	-	0.90	-	-1.57	-
PC97	0.027	-	-0.13	-	0.00	-	-0.15	-
PC98	0.282	-	1.18	-	0.17	-	-0.49	-

Legend
- - non-significant
- * significant at 0.05
- ** significant at 0.01
- *** significant at 0.001

Figure 30a. Observed and projected PC1 scores based on the standardized covariance matrix with the sampling variances of the means (separate basins).

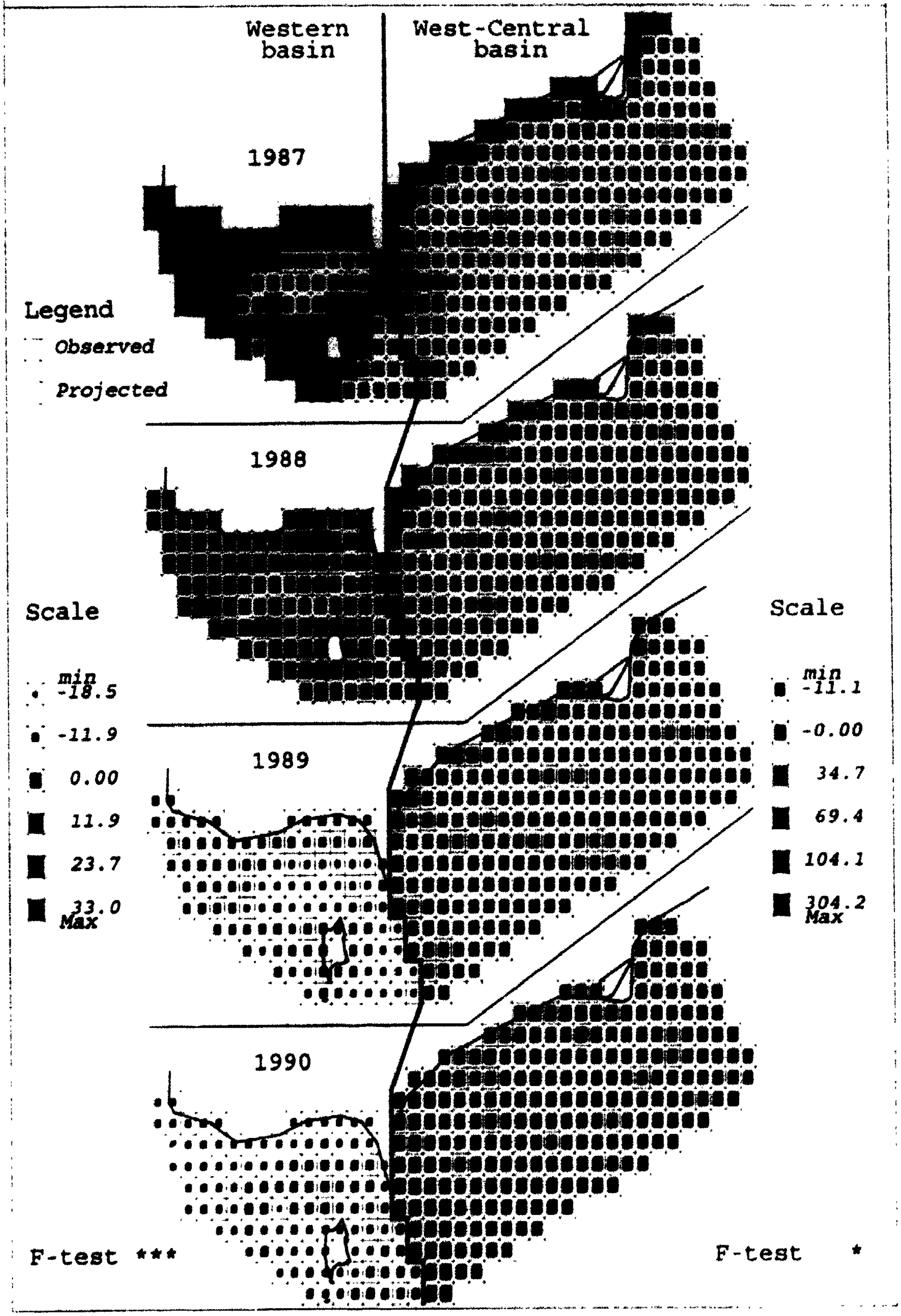


Figure 30b. Observed and projected PC2 scores based on the standardized covariance matrix with the sampling variances of the means (separate basins).

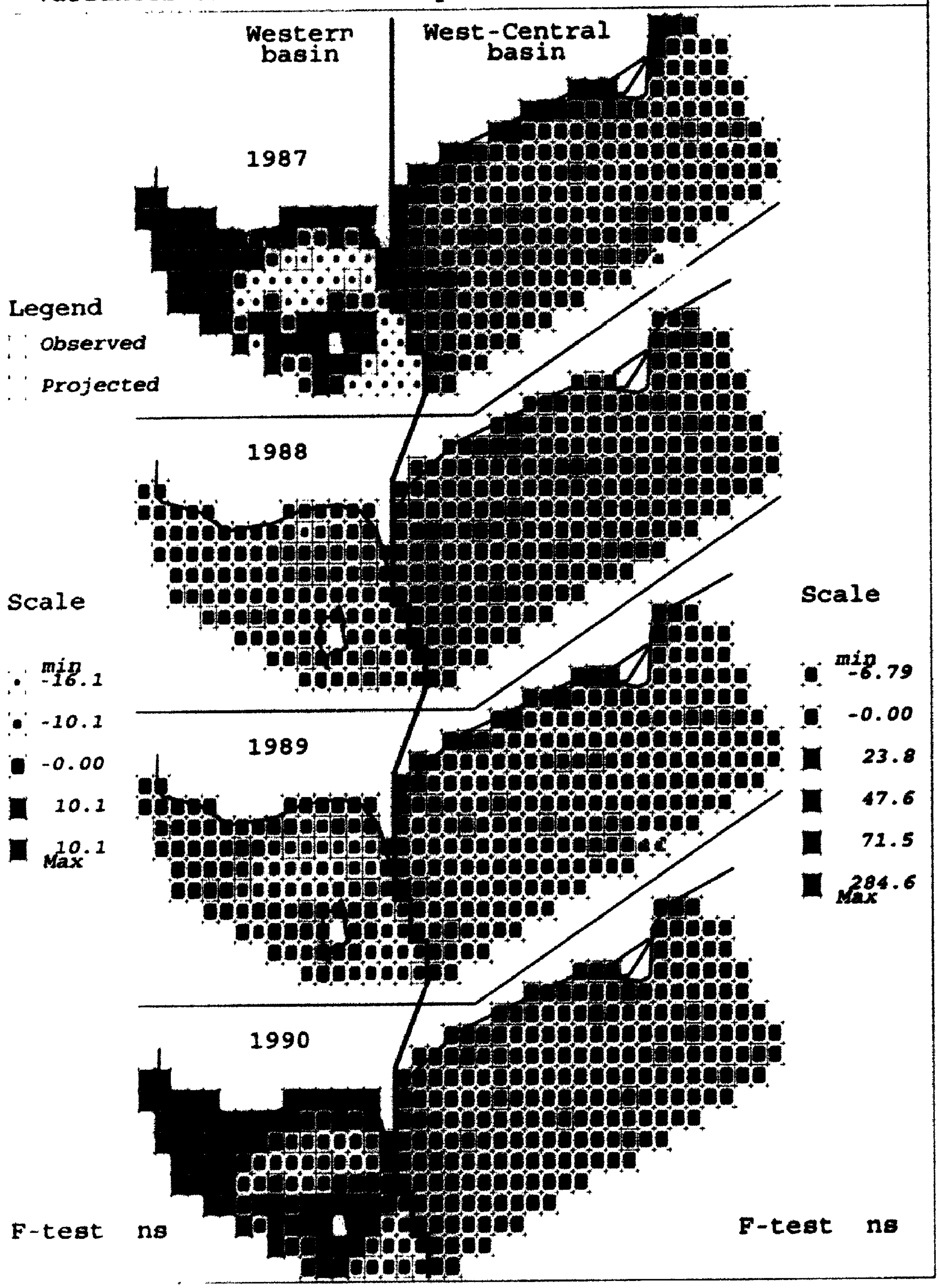


Figure 30c. Observed and projected PC3 scores based on the standardized covariance matrix with the sampling variances of the means (separate basins).

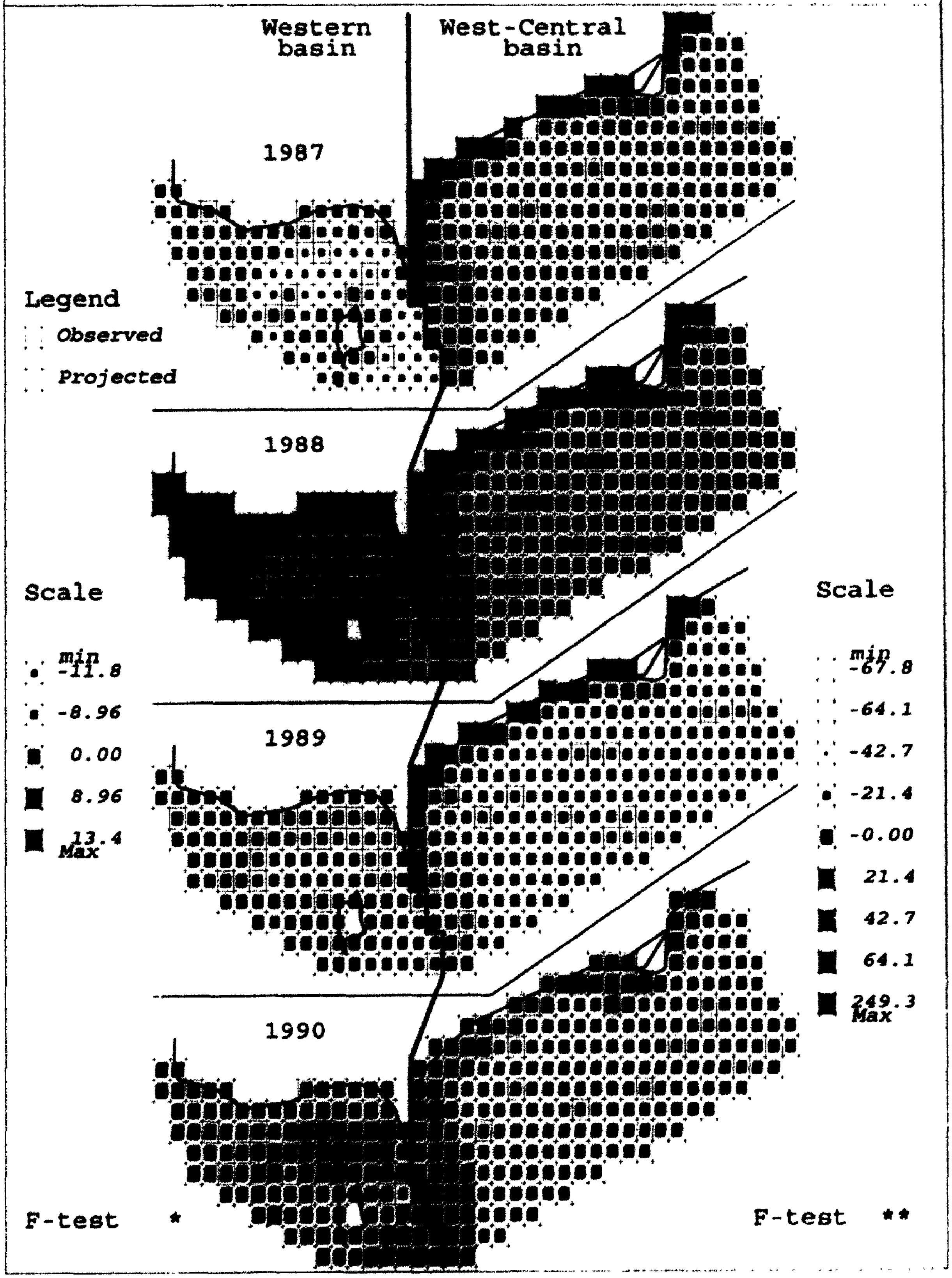


Figure 30d. Observed and projected PC4 scores based on the standardized covariance matrix with the sampling variances of the means (separate basins).

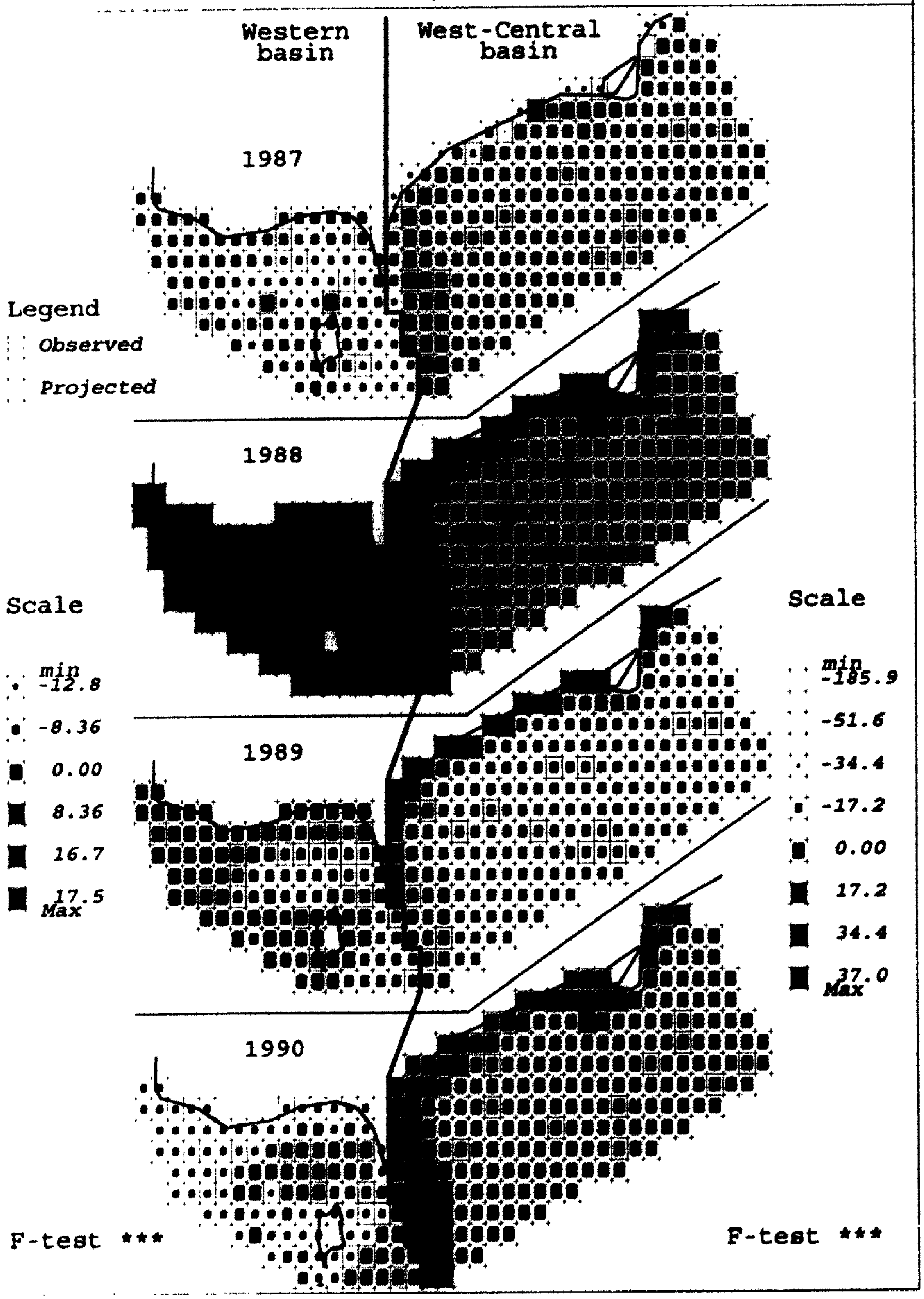


Figure 30e. Observed and projected PC5 scores based on the standardized covariance matrix with the sampling variances of the means (separate basins).

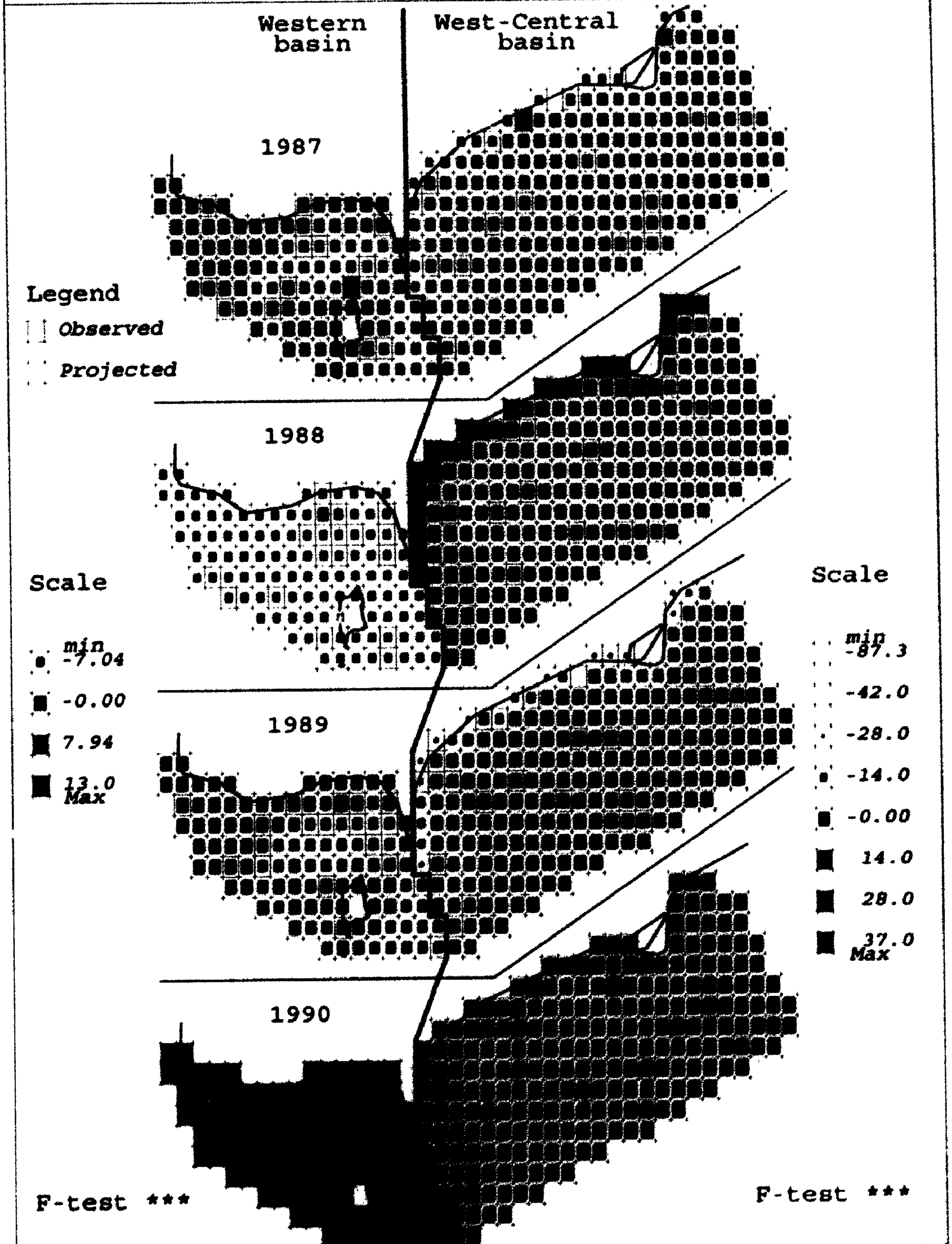


Figure 30f. Observed and projected PC6 scores based on the standardized covariance matrix with the sampling variances of the means (separate basins).

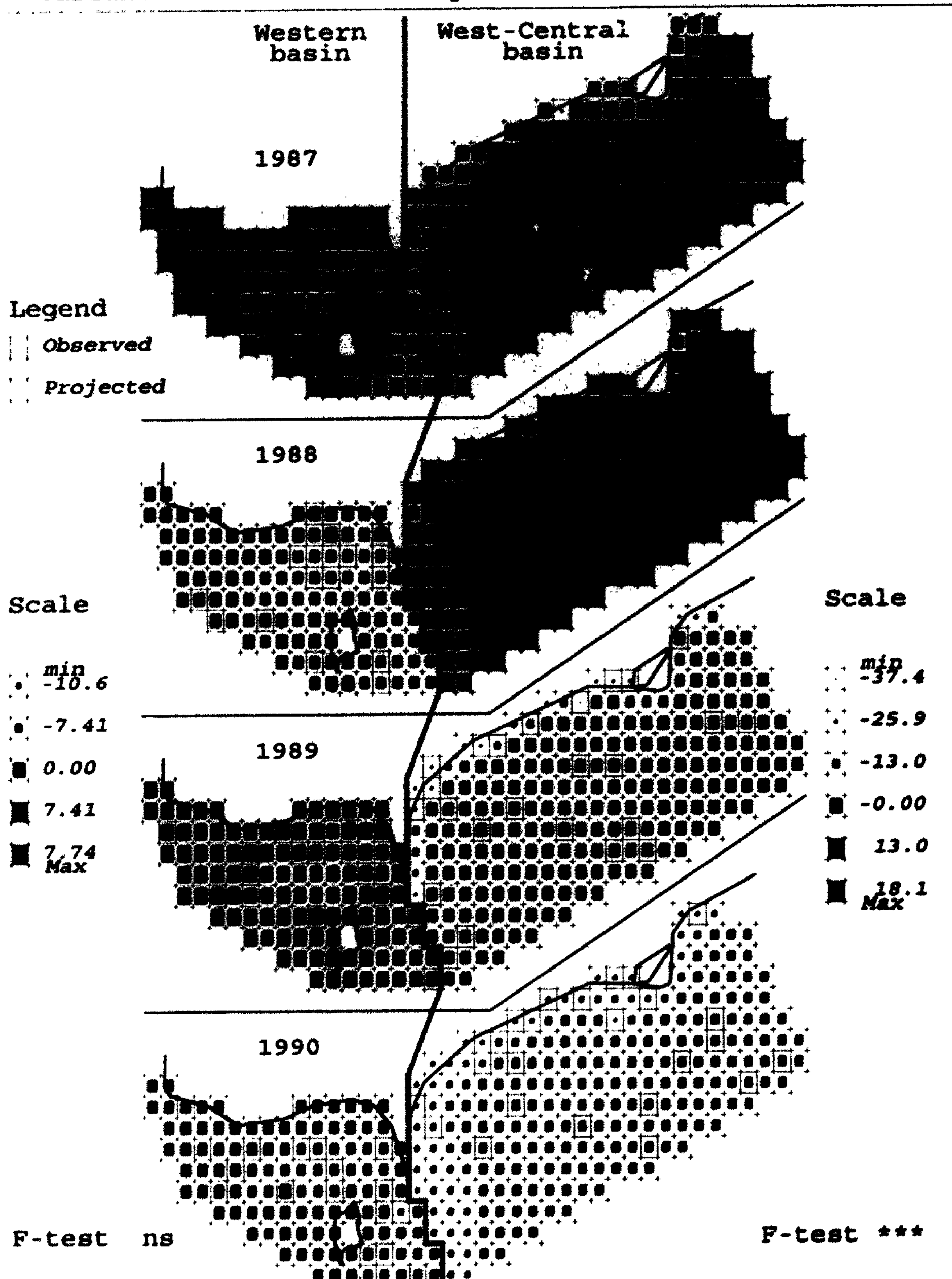


Figure 30g. Observed and projected PC7 scores based on the standardized covariance matrix with the sampling variances of the means (separate basins).

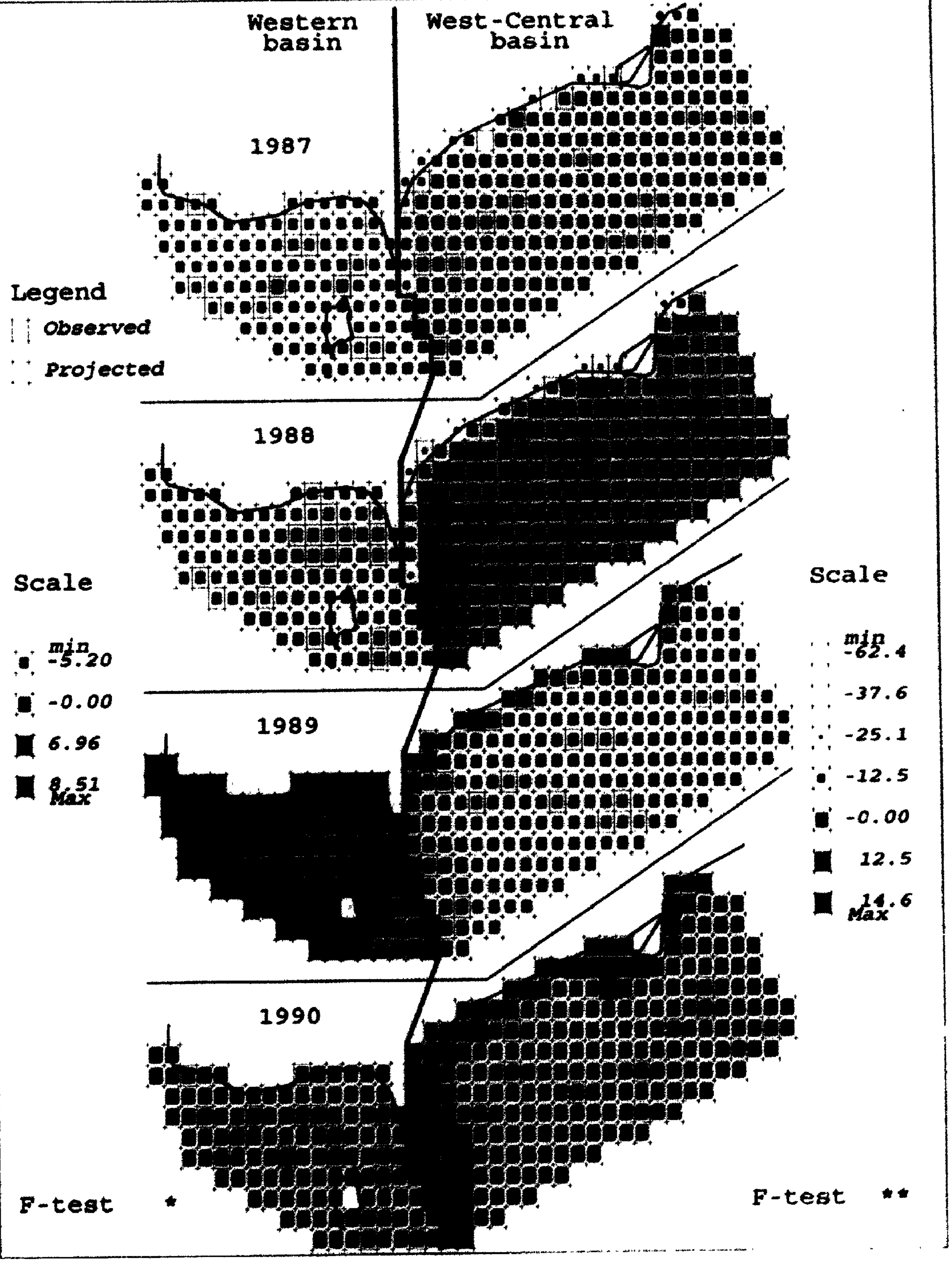


Figure 30h. Observed and projected PC8 scores based on the standardized covariance matrix with the sampling variances of the means (separate basins).

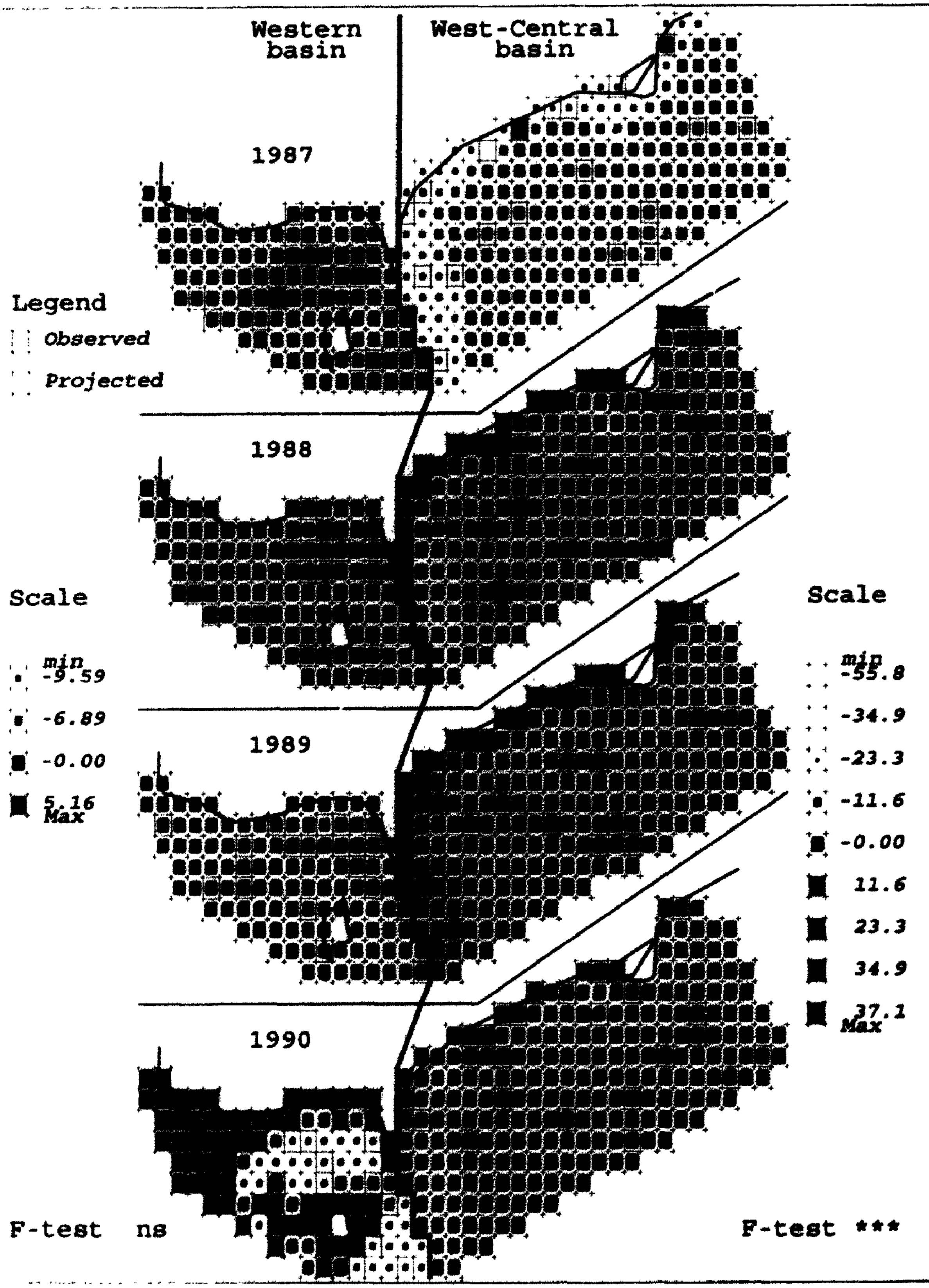


Figure 31a. Average PC1 scores based on the standardized covariance matrix with the sampling variances of the means for the Western basin and by stratum.

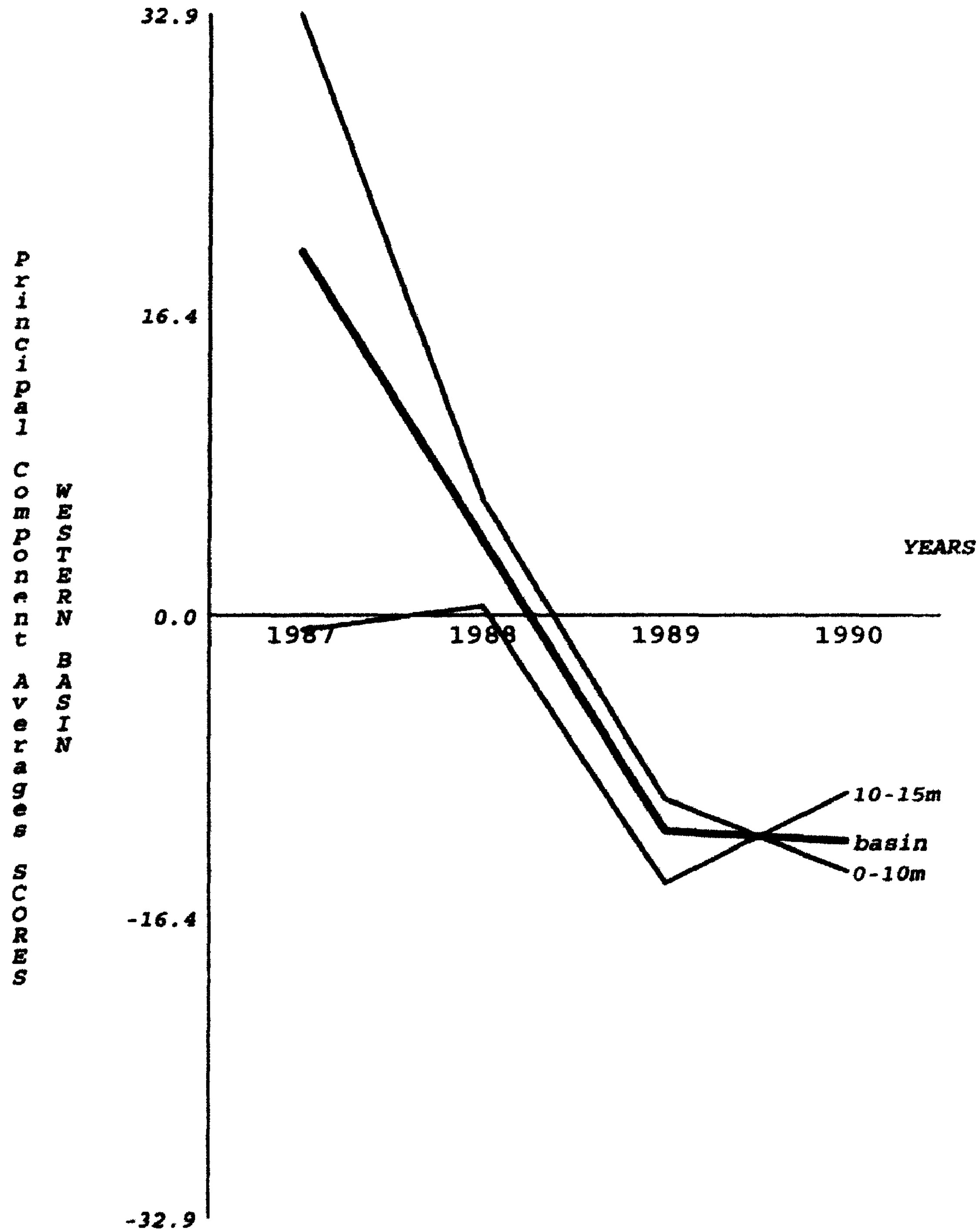


Figure 31b. Average PC2 scores based on the standardized covariance matrix with the sampling variances of the means for the Western basin and by stratum.

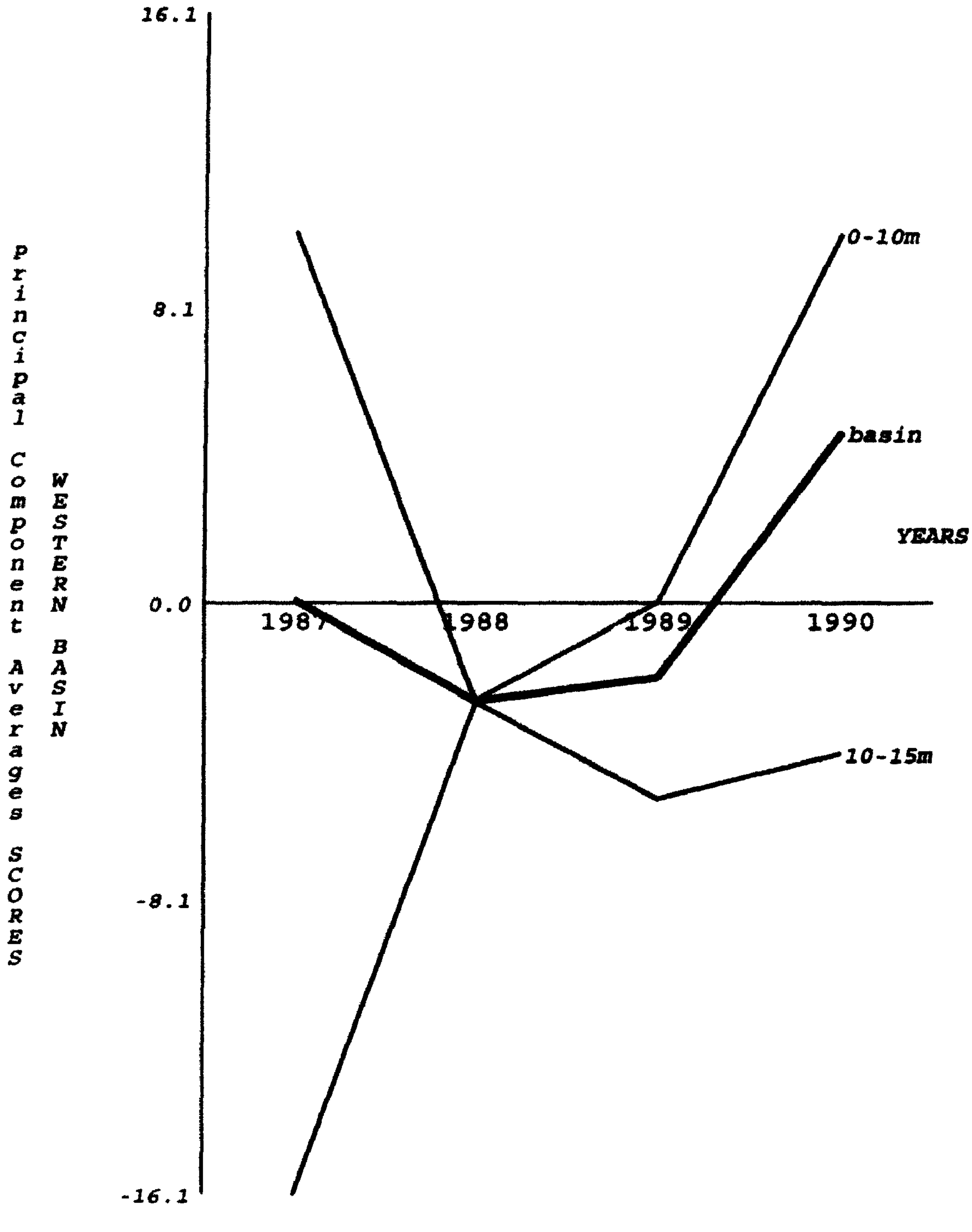


Figure 31c. Average PC3 scores based on the standardized covariance matrix with the sampling variances of the means for the Western basin and by stratum.

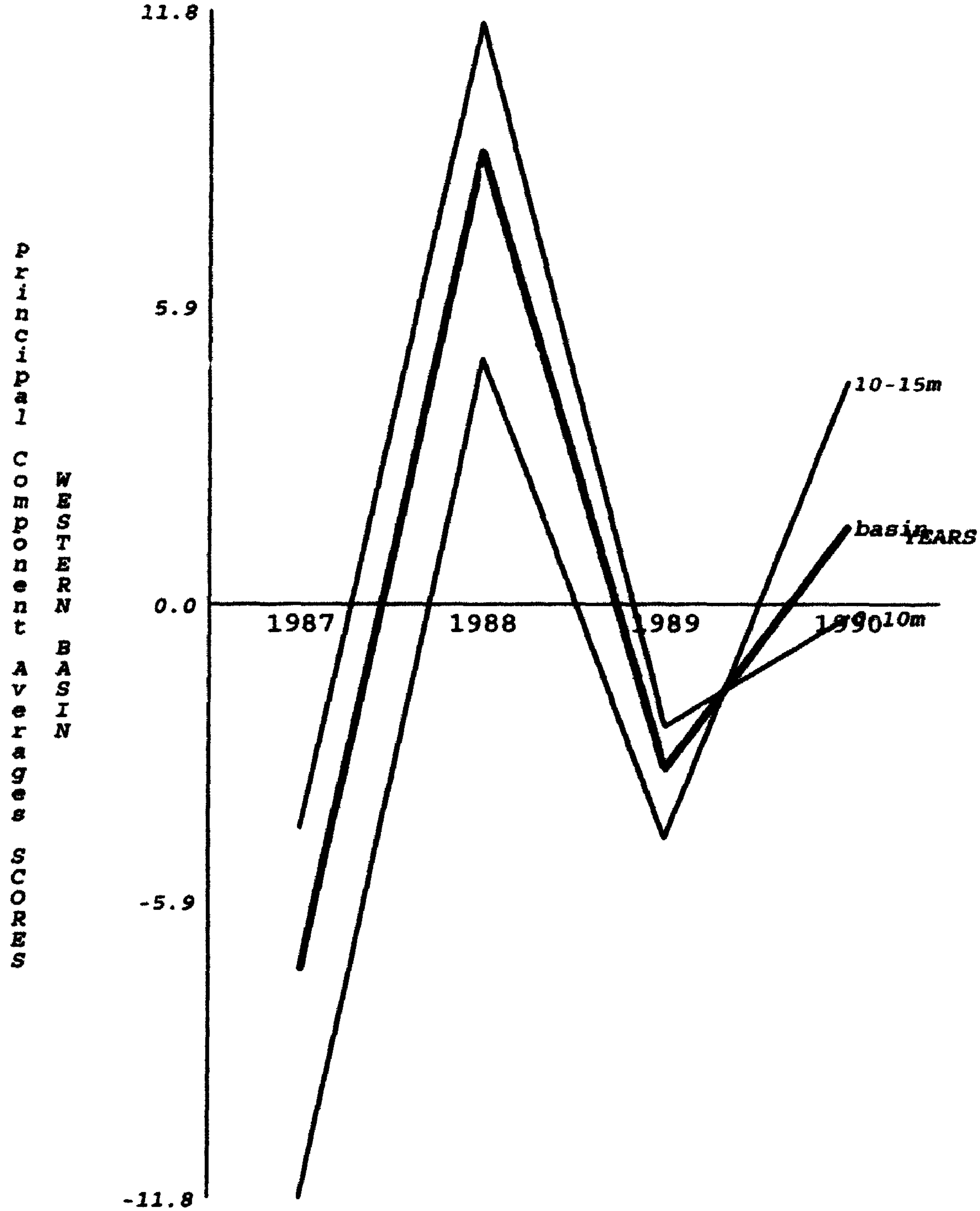


Figure 31d. Average PC4 scores based on the standardized covariance matrix with the sampling variances of the means for the Western basin and by stratum.

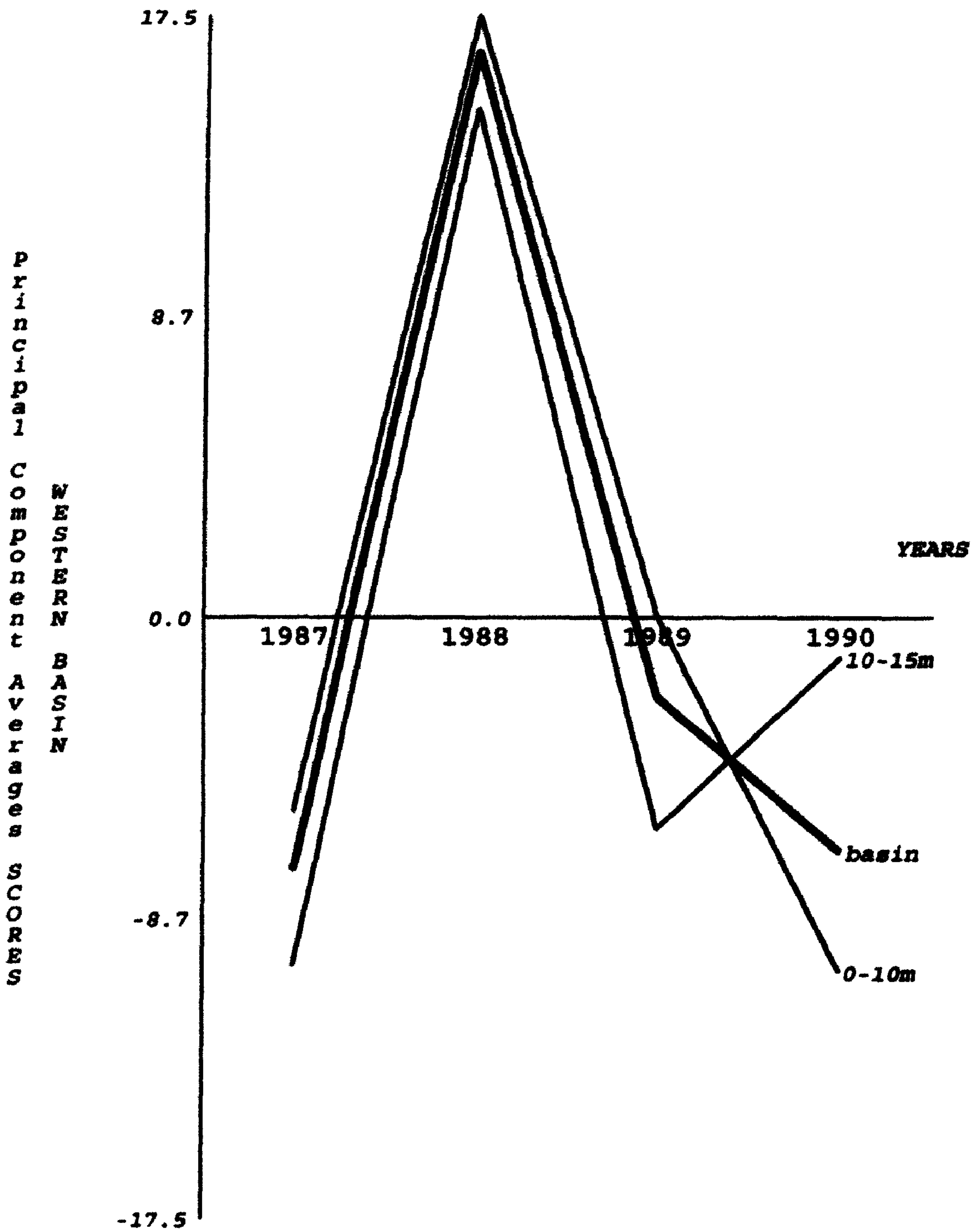


Figure 31e. Average PC5 scores based on the standardized covariance matrix with the sampling variances of the means for the Western basin and by stratum.

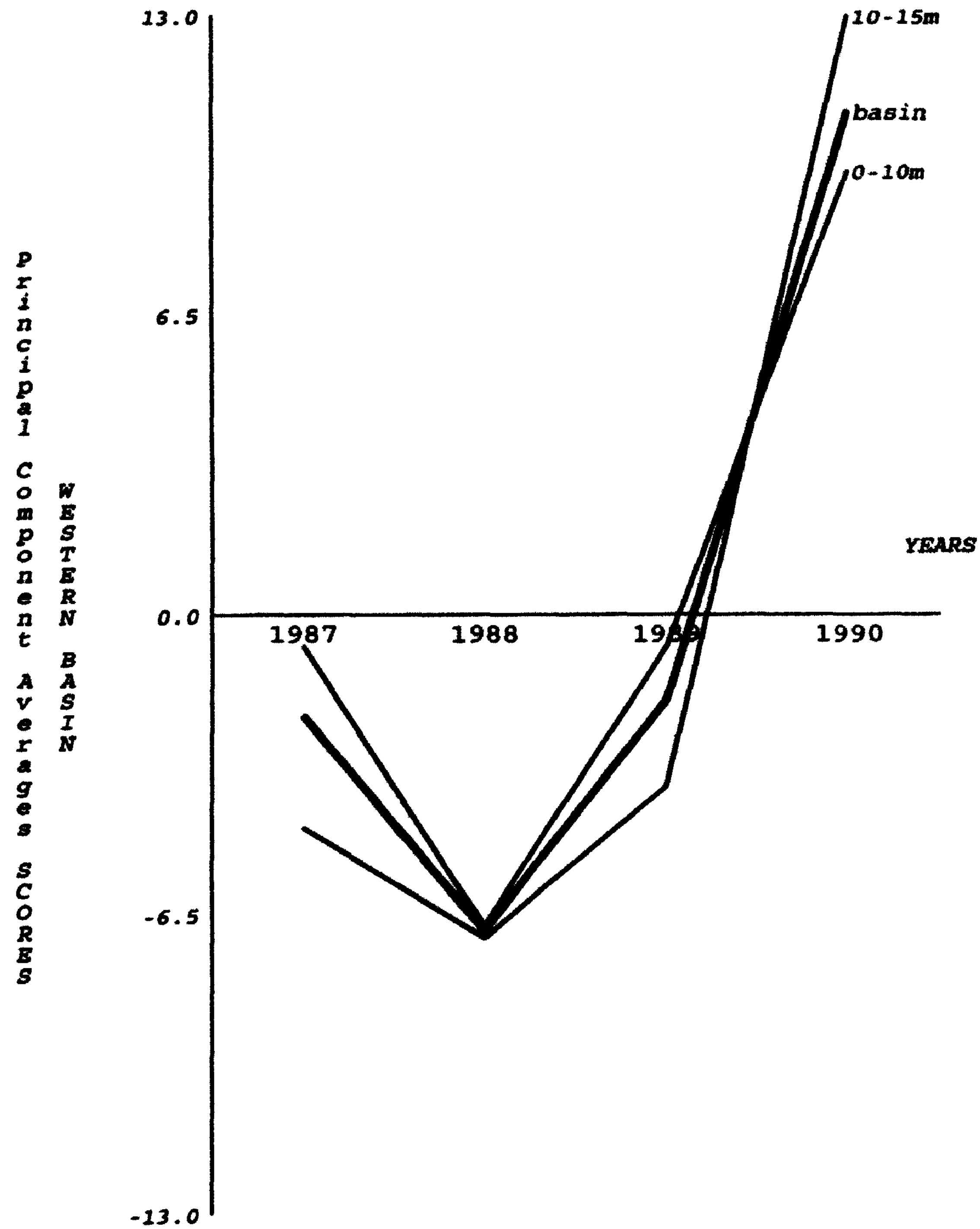


Figure 31f. Average PC6 scores based on the standardized covariance matrix with the sampling variances of the means for the Western basin and by stratum.

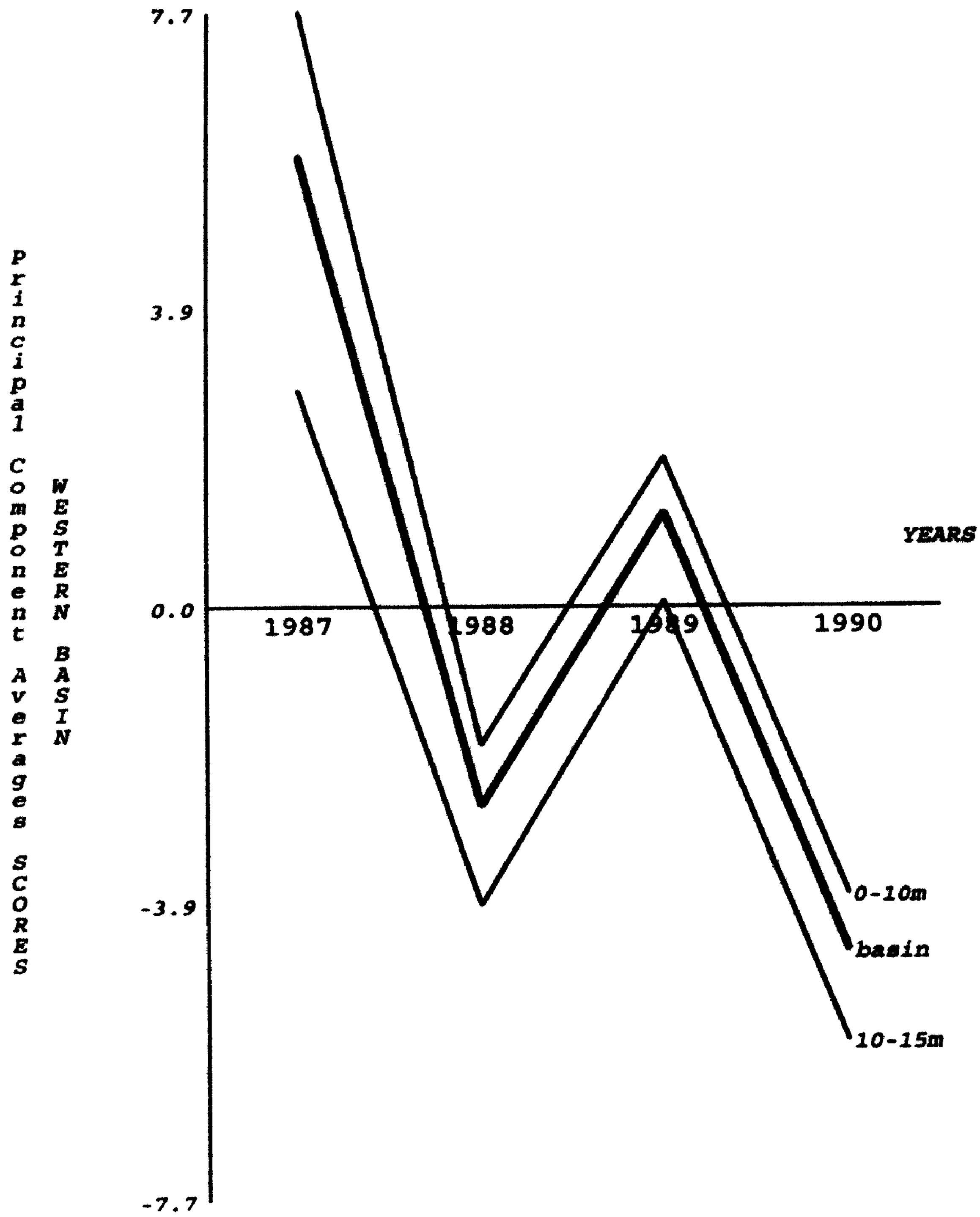


Figure 31g. Average PC7 scores based on the standardized covariance matrix with the sampling variances of the means for the Western basin and by stratum.

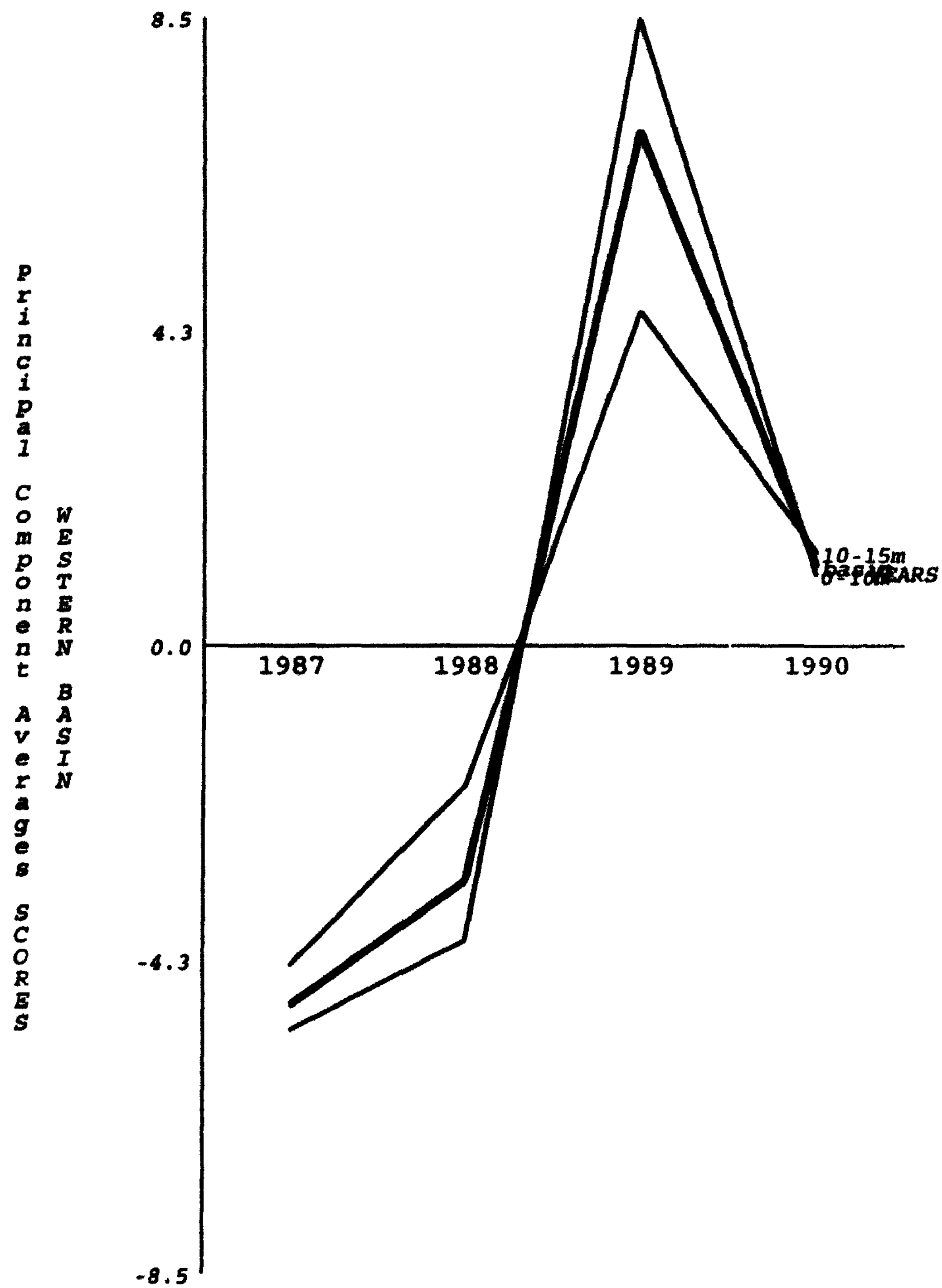


Figure 31h. Average PC8 scores based on the standardized covariance matrix with the sampling variances of the means for the Western basin and by stratum.

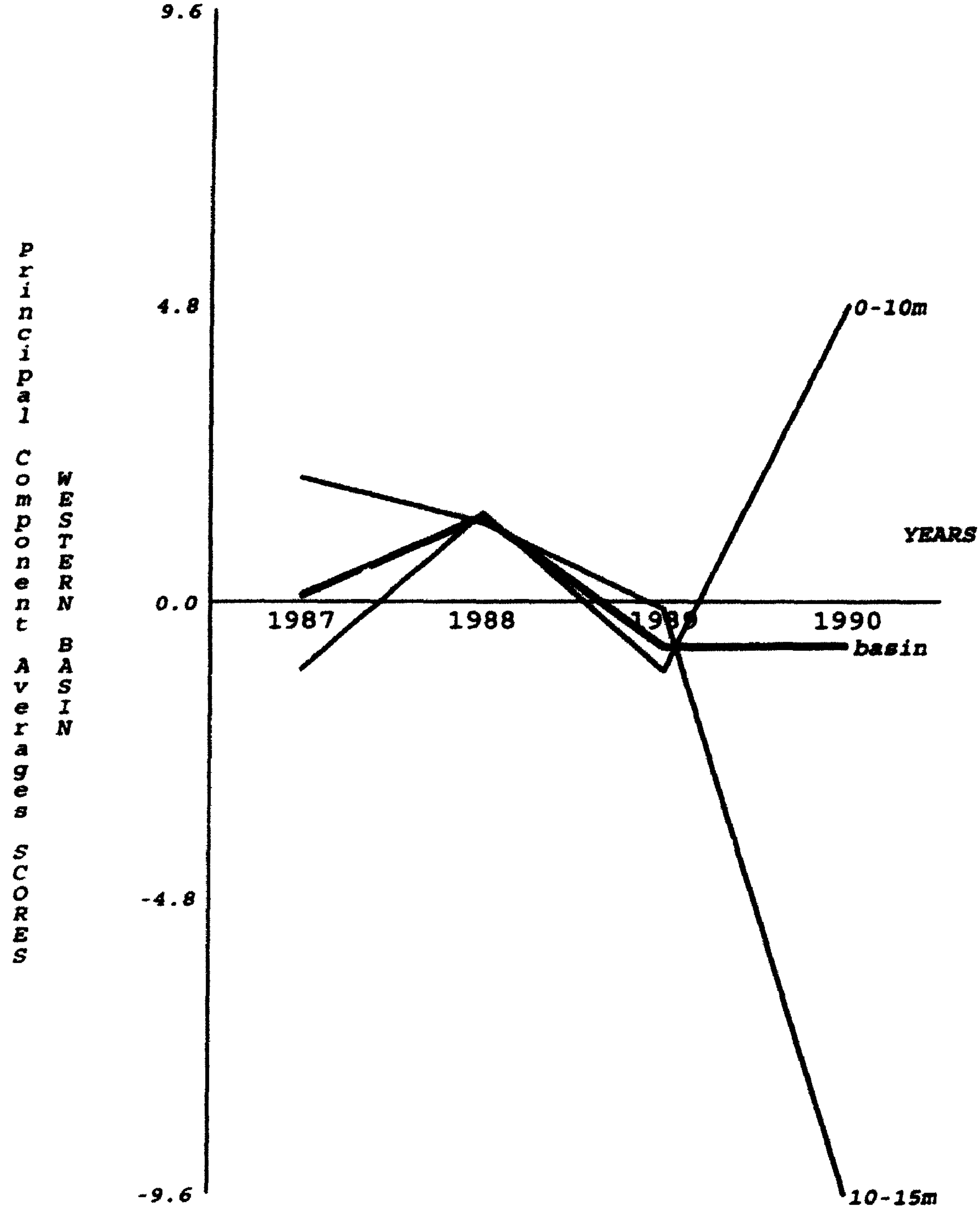


Figure 32a. Average PC1 scores based on the standardized covariance matrix with the sampling variances of the means for the West-Central basin and by stratum.

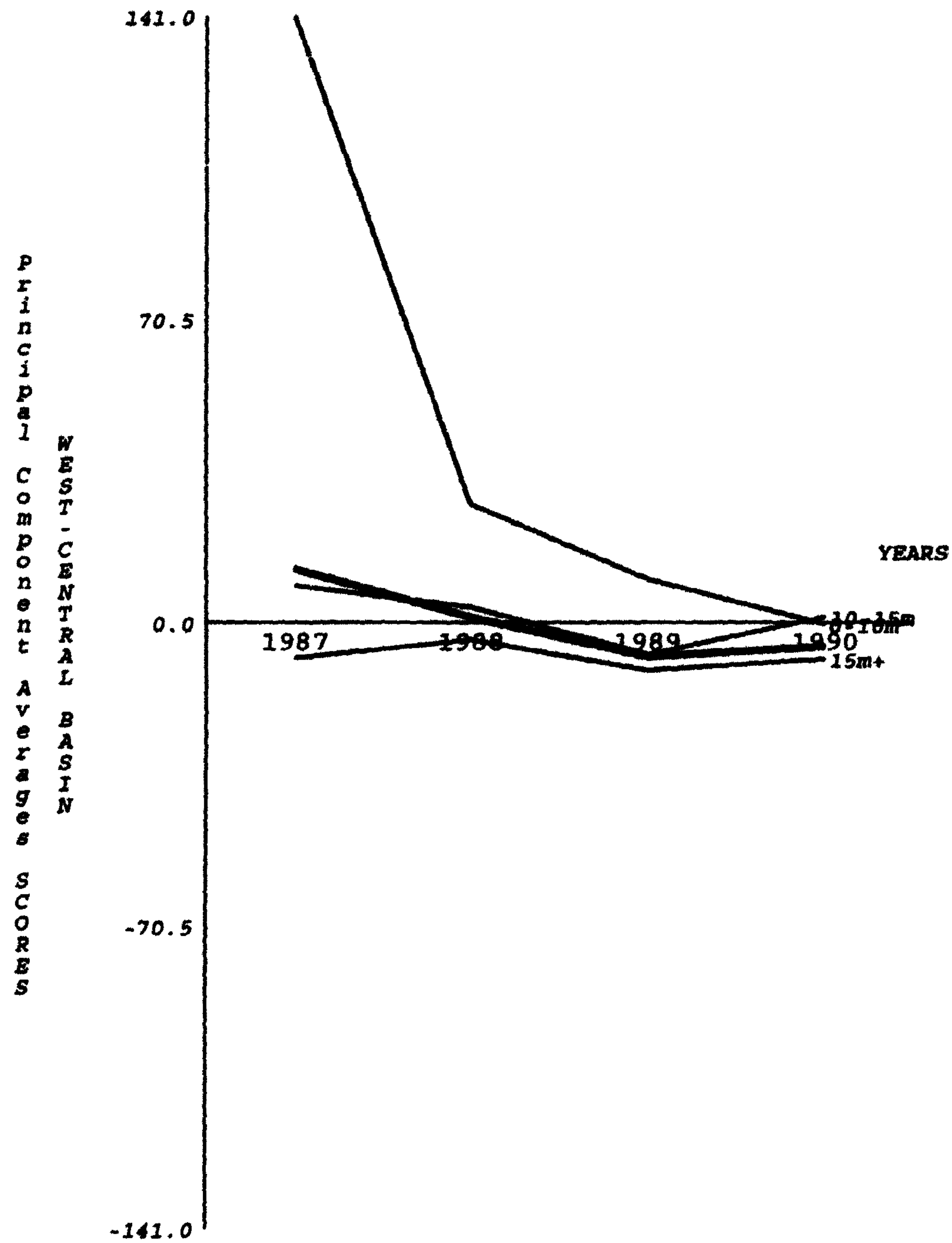


Figure 32b. Average PC2 scores based on the standardized covariance matrix with the sampling variances of the means for the West-Central basin and by stratum.

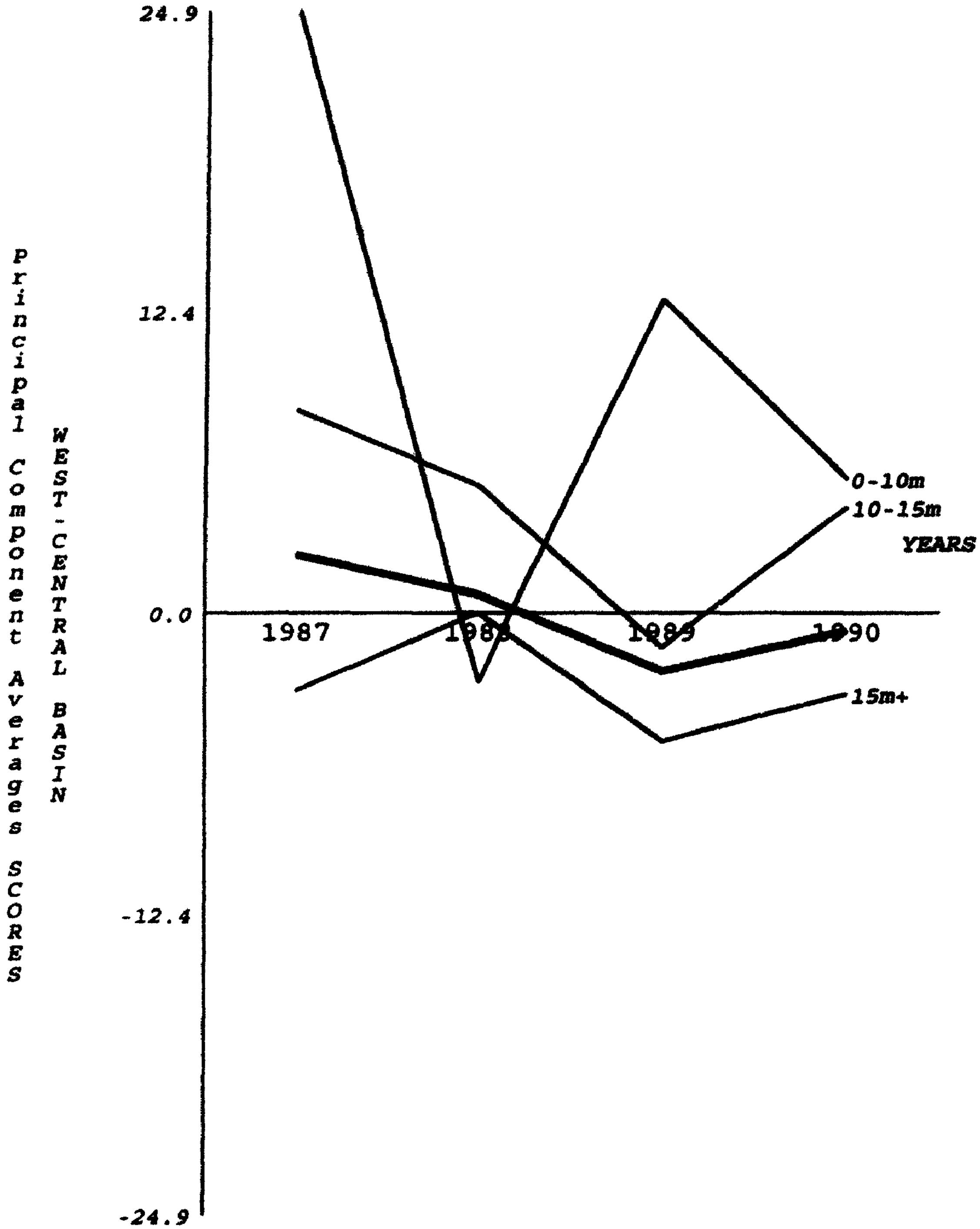


Figure 32c. Average PC3 scores based on the standardized covariance matrix with the sampling variances of the means for the West-Central basin and by stratum.

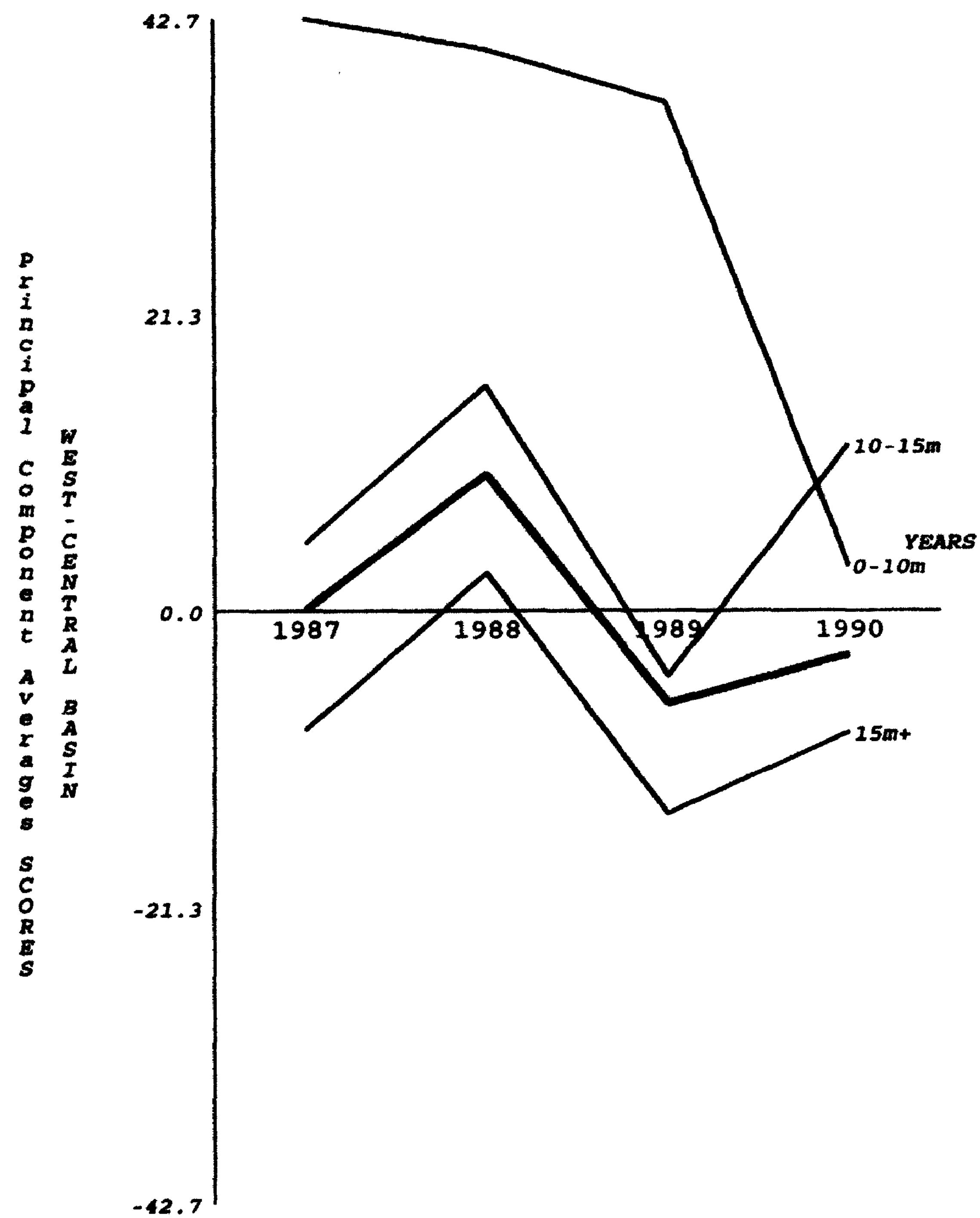


Figure 32d. Average PC4 scores based on the standardized covariance matrix with the sampling variances of the means for the West-Central basin and by stratum.

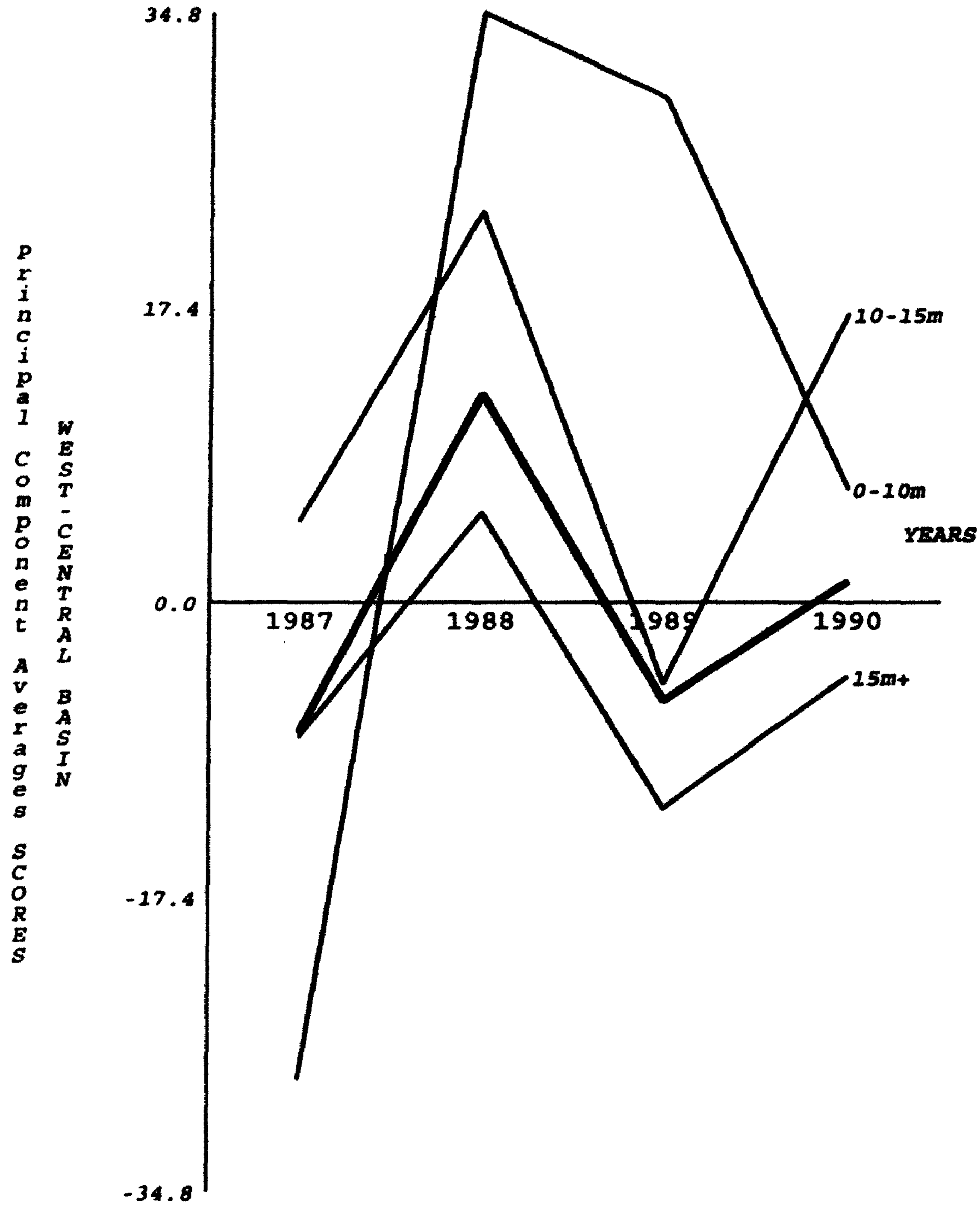


Figure 32e. Average PC5 scores based on the standardized covariance matrix with the sampling variances of the means for the West-Central basin and by stratum.

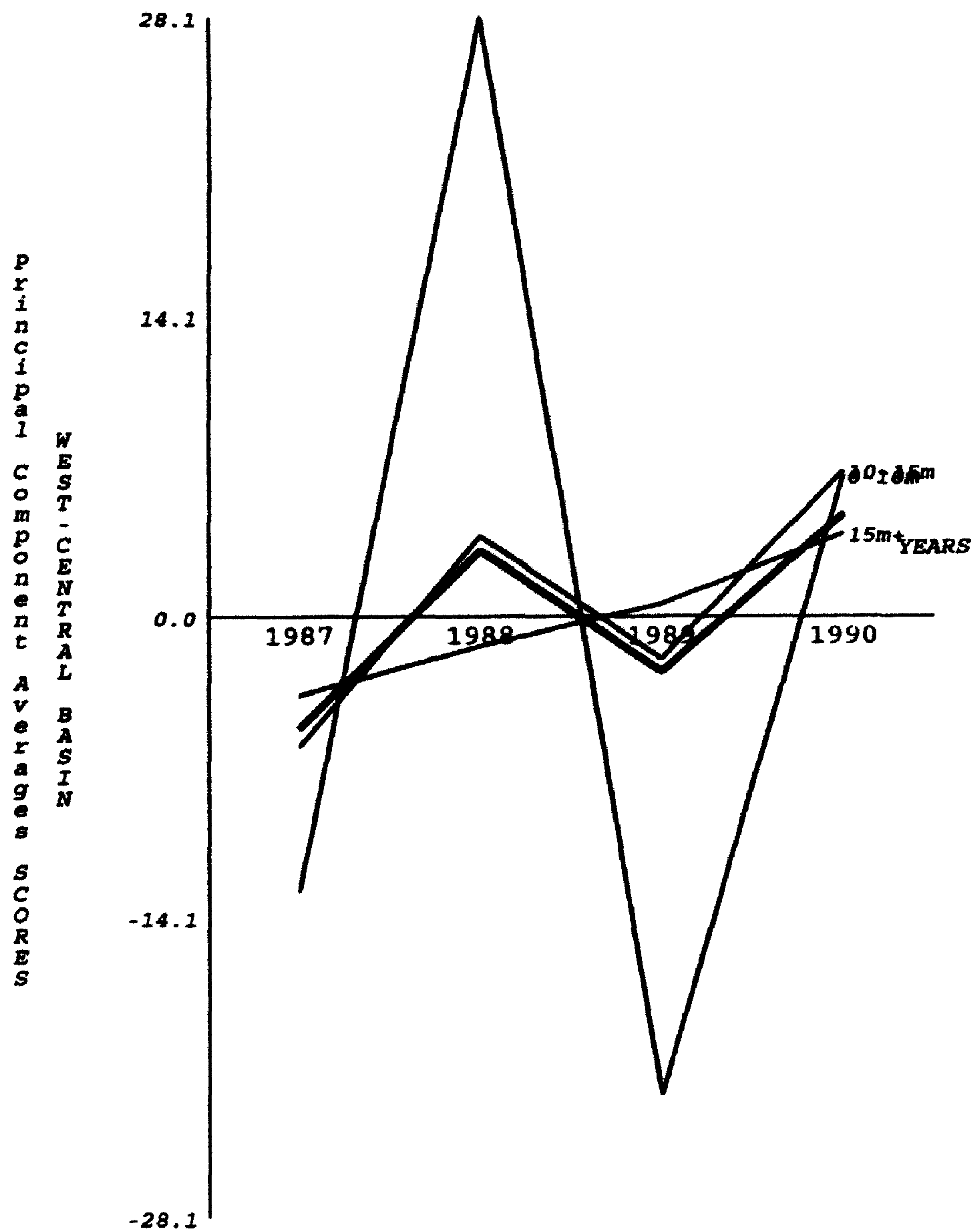


Figure 32f. Average PC6 scores based on the standardized covariance matrix with the sampling variances of the means for the West-Central basin and by stratum.

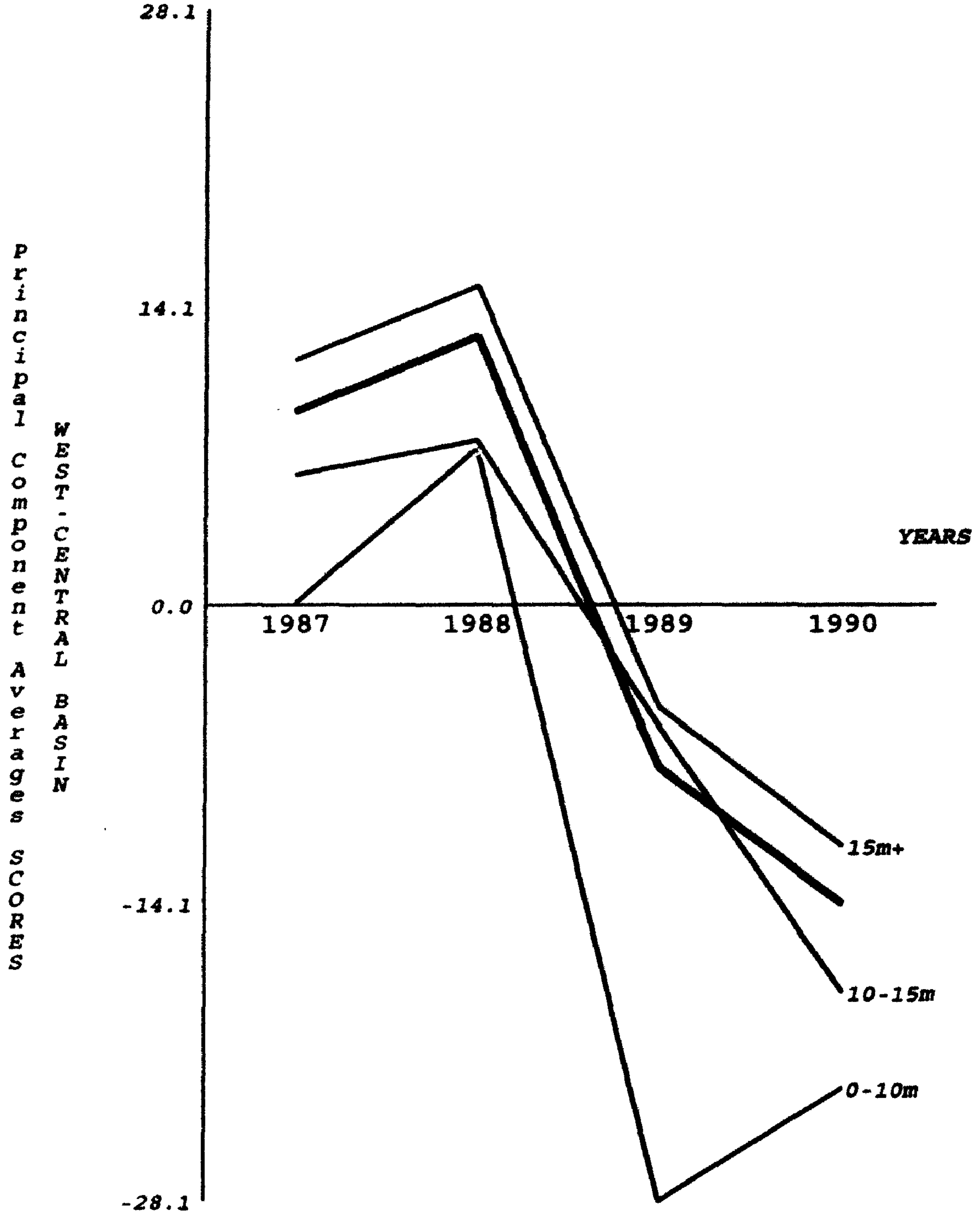


Figure 32g. Average PC7 scores based on the standardized covariance matrix with the sampling variances of the means for the West-Central basin and by stratum.

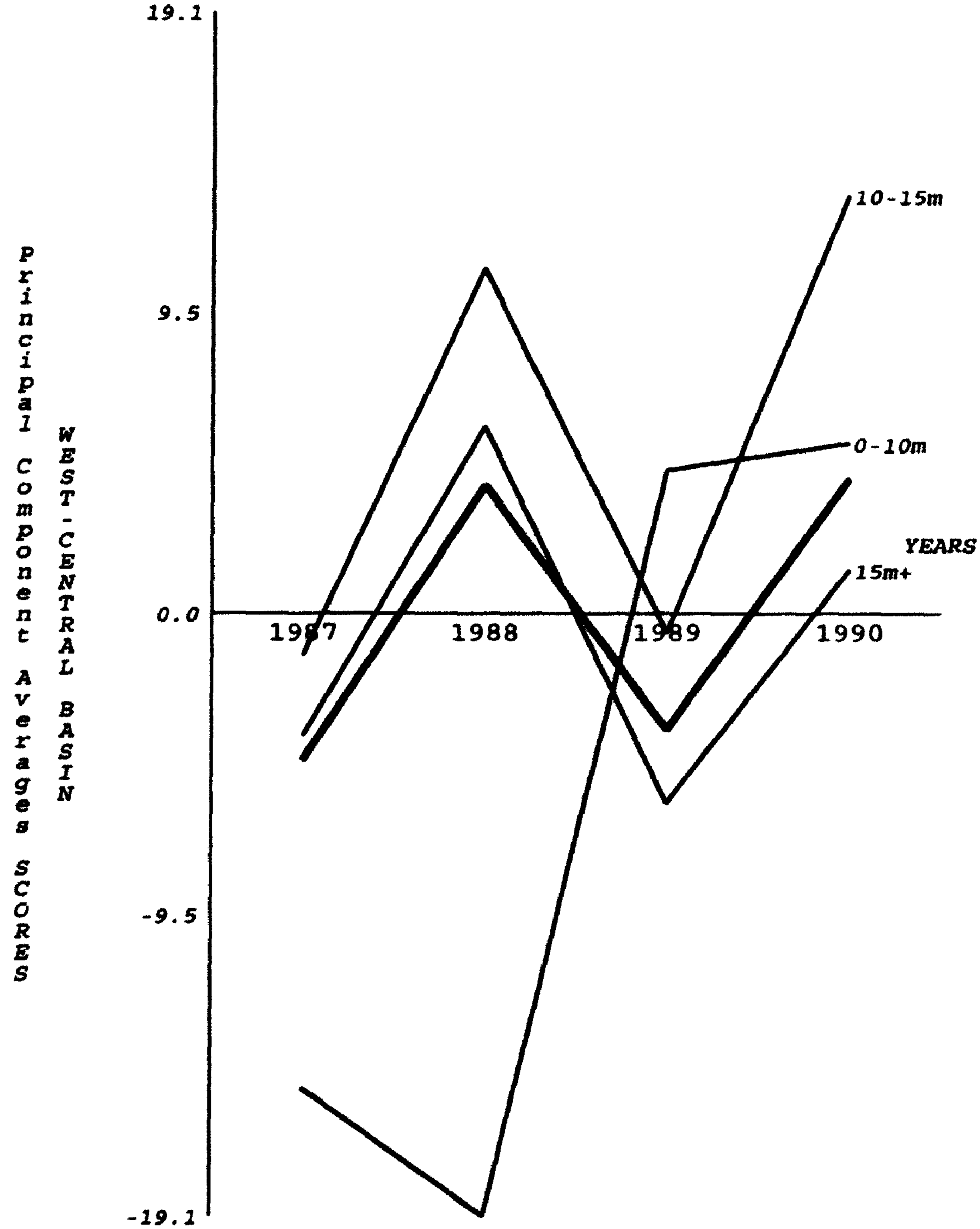
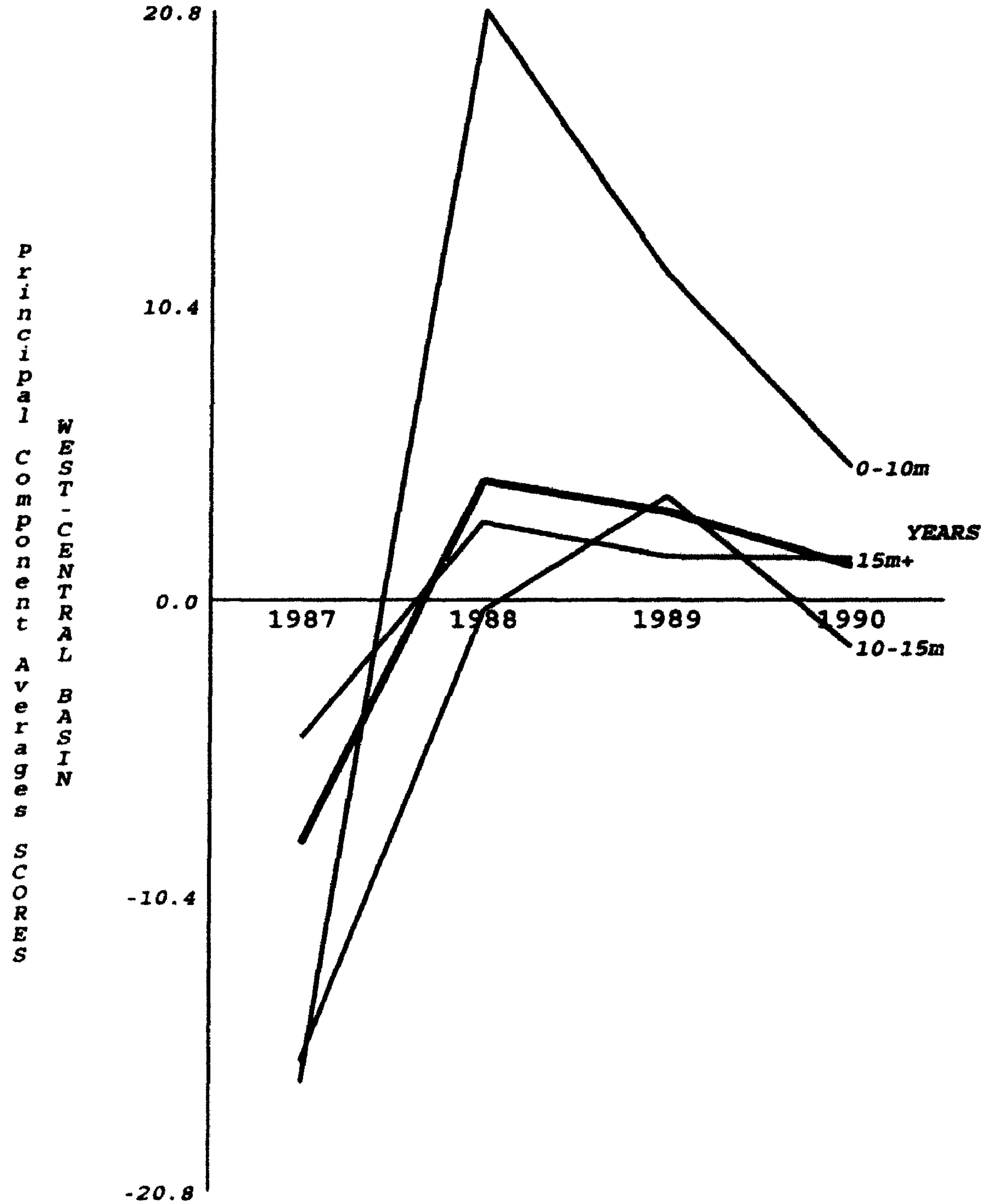


Figure 32h. Average PC8 scores based on the standardized covariance matrix with the sampling variances of the means for the West-Central basin and by stratum.



5. Discussion and conclusion

5.1 Principal Component Analysis of change

The standardization of the covariance matrix with the sampling variances (section 3.2) was described as a method which facilitates the detection of change. This will be shown after a discussion on the technique.

With this standardization technique, if a population (not structured) is sampled once (one year only), the sampling variances of the means would be directly proportional to the actual values of the variances since there is only a constant factor of $(1/n_t - 1/N)$ that is used to get the sampling variances from the sample variances (equation **(13)**) of all variables. The derived principal components from the PCA on COV/SV will be exactly correlated with those derived from a PCA on COR (the proportionality will be given by the squared root of the constant factor for all variables). Then, correlated patterns of variation between observations (here only the units) would emerge as principal components. With the PCA on COV, patterns of covariation between observations (units) would emerge as principal components. The difference between the two techniques will be due to the difference in the diagonal values on the covariance matrix (such as Tables 10a and 10c, or 11a and 11c).

If a population (not structured) is sampled over many years, the sampling variance now integrates the information from all these years (equation (23)). The resulting scaler is the analog of the Mean Squared Error in a two-way analysis of variance (appendix 2) with the UNIT and YEAR main factors taken into account. The PCA on COV/SV will now differ most of the time from a PCA on COR. As the PCA on COV, or COR, will promote emergence of the covariated, or correlated, patterns of variation between observations not adjusted for between years variability, the resulting principal components will show by the side the between years variability but not as an explicit derivation.

The PCA on COV/SV would differ from the two other types by weighting the variables in such a way that between years and/or between units patterns (if any) are emphasized on specific principal components.

To show this, a hypothetical case may be studied. Suppose that two variables are measured on two occasions on independent units. Let say for convenience that two units per year are observed. The following results are chosen and presented in Table 19.

Table 19. A hypothetical example to show the difference between the three types of PCA.

Year	unit	V1	V2
1	1	1	1
	2	4	18
	mean	2.50	9.50
	std	2.12	12.02
2	3	7	3
	4	10	20
	mean	8.50	11.50
	std	2.12	12.02

These numbers are selected to show a greater variability and lower mean variability in the second variable (V2), no particular correlation. The first variable shows a large absolute change (six units of variation) in average while the second experiences little change (two units of variation).

A PCA on covariance would start with the following matrix

	V1	V2
V1	15.00000000	21.00000000
V2	21.00000000	97.66666667

Here, the first variable has an influential weight of 0.2663 compared to the second variable with 1.7338.

The first principal component is getting 91.1 % of the total variance and the two PC scores have the following expressions:

PC1 =(0.232881)*V1 + (0.972505)*V2;

PC2 =(0.972505)*V1 + (-.232881)*V2;

The first variable expressed 37.1 % of its variance on the PC1 while the second expressed 99.4 %.

In a PCA on COV/SV, the sampling variance of the means may be computed without the finite population correction (1/*N*). Since there is no paired units, the two values are 2.25 for V1 and 72.25 for V2. Standardized variables, SV1 and SV2, are computed and submitted to a PCA on covariance.

A PCA on COV/SV would start with the following matrix

	SV1	SV2
SV1	6.666666667	1.647058824
SV2	1.647058824	1.351787774

Here, the first variable has an influential weight of 1.6628 compared to the second variable with 0.3372.

The first principal component is explaining 89.0 % of the total variance and the two PC scores have the following expressions:

PC1 =(0.961765)*SV1 + (-.273878)*SV2;

PC2 =(0.273878)*SV1 + (0.961765)*SV2;

The first variable expressed 99.0 % of its variance on the PC1 while the second expressed 39.6 %.

In a PCA on COR, variables are standardized during the process and will be referred with Z1 and Z2.

A PCA on COR would start with the following matrix

	Z1	Z2
Z1	1.0000	0.5487
Z2	0.5487	1.0000

Here, both variables have equal influential weight. The first principal component is getting 77.4 % of the total variance and the two PC scores have the following expressions:

PC1 =(0.707107)*Z1 + (0.707107)*Z2;

PC2 =(0.707107)*Z1 + (-.707107)*Z2;

Both variables expressed 77.4 % of their variance on the PC1.

In this hypothetical example, the PCA on covariance clearly derived a first principal component that is associated with the variable with the largest variance while first principal component from the PCA on COR takes account the correlation between the four (two years by two units' observations.

In analysis of variance, the partition of the total variance (variance of the observations not structured by year or unit) is given in terms of residual variance (MSE term), main effects and interactions. The action of the PCA on COV/SV is to increase the relative weight of a variable as the importance of any main effects and/or interactions increases for that variable. On the other hand, the minimum weight a variable could get is when no difference between years, no differences between units and years occur and the observed variance is due to variation between observations (not structured). Principal components that could be derived from this type of analysis are not strait classified patterns of between years, between units, interactions or between observations. They may be mixture of effects. But this PCA technique has the advantage to be explicitly built to search for principal components showing covariated pacterns of variation associated with the main effects and/or interactions of interest. If no such effects would be present, this PCA would again do the same results as in PCA on COR where only correlated patterns of variation between observations are derived.

If a stratified population was sampled on many years, the sampling variances used for the standardization in PCA on COV/SV is given by equation (49) which takes into account four levels of variations : the between observations, the between units, the between years and the between strata. All these main effects or related mixtures are derived explicitly in the PCA on COV/SV.

This PCA type would be an instrument for community ecology since the resulting principal components would be closely related to variation between individual units of sampling, variation in time and variation in habitat (stratification). But in the present study, some restrictions in the meaning of the measure mentioned in the first chapter limits the study of between species interactions.

Tables 16a and 16b show the importance of the principal components (eigen values in percent of the total variation) and the statistical significance for the between years F-test. All types of PCA show differences in their most important principal components. The first eight PC's of each type, account for the major between years patterns in both basins. Tables 17a and 17b will be used to show the action of each PCA type.

As shown in Tables 10a, 10b and 10c for the Western basin, white perch, yellow perch, freshwater drum, alewife and walleye have important influential weights for the PCA on COV type. The first, second and third PC on COV express important proportion of the variance of these four first species. Walleye is found in the fourth and fifth PC. Since Table 13 (and Table 17a) reported significant changes for the five species, it is expected to see the principal components associated with these species to be also nearly significant, which it is the case.

In PCA with COR, white perch is associated with the second and first PC, the first and second for yellow perch and freshwater drum. The first PC is significant at 0.001 but not the second PC. The species-mesh variables associated with the first PC on covariance are not necessarily the same in the PC on correlations. For example, white perch 70mm-89mm variables decrease in expression from PCA on COV to PCA on COR and white perch 32mm-51mm do the reverse. This is the possible effect of the correlations differently weighted in the two analyses. This is clear that these two types of principal components produce different results.

The PCA on COV/SV type restructured the species-mesh variables with alewife 32-57mm, white perch 32-38mm, walleye 32-45mm, yellow perch 32-45mm and middle mesh size freshwater drum, white sucker 64-76mm and white bass 45mm, to show a significant trend of change at 0.001. Almost all these species-mesh variables show individually significant change (Tables 13 or 17a). The white perch 45-114mm, yellow perch 32, 51-57mm, freshwater drum 57mm are from species-mesh variables that were largely expressed in PC1 on covariance and are now expressed on the second PC on covariance standardized with the sampling variances. These three species did not have enough large synchronized variation to emerge as the first PC. Species such as alewife and white bass which were not specific to any of the PC on COV studied or were attached to less important PC on COV showed a increase in their specificity generally to an important PC in the PCA on COV/SV in this basin.

The West-Central basin was a composition of three depth strata. The depth variability is more accentuated than in the previous basin. Tables 11a, 11b and 11c showed that only three species, white perch, yellow perch and freshwater drum, got important weights for the PCA on COV type. PC1, PC2 and PC3 from PCA on COV express important proportion of the variance of these species (Table 17b). It is expected to see the principal components associated with these species also nearly significant, since white perch and yellow perch showed significant changes.

In PCA with correlation, the white perch and yellow perch are associated with the first, the second and the fourth PC, freshwater drum being associated with the first PC only. alewife variables are largely expressed in the first PC.

The PCA on COV/SV type restructured the species-mesh variables with alewife 32-127mm, white perch 38mm, walleye 51mm and white bass 32-45mm, to show a significant trend of change at 0.05 only. Few of these species-mesh variables show individually significant change (Table 17b). The second PC from this type of standardization is also not significant for change. Alewife and white bass species-mesh variables are associated with this PC. The PC3 and PC4 account for significant change with white perch and freshwater drum variables. PC5 is associated with few white bass variables and PC6 is typically representing the variation of the yellow perch.

The second principal component in the Western basin and the first and second in the West-Central basin are showing unsignificant or only significant change at 0.05. These results would be enough to reconsider the technique COV/SV since the PCA on COV offered significant first four principal components of each basin (Tables 16a and 16b).

But the results from the PCA on COV/SV have to be placed in another perspective. Table 20 shows the significance of F-tests performed in strata within the basins on the appropriate principal components. Also, Figures 31b, 32a and 32b show the fluctuation of the average PC scores with time at the stratum level and for the overall basin. The overall low significant results hide significant change occuring in the deepest stratum of each basin. Figures 31b and 32b show change occuring with different patterns in each stratum. This would support the fact that the PCA on COV/SV promotes not only principal components of change but also PC of habitats and/or PC of changes within specific habitats (interaction stratification and time) as well as basic correlated patterns between observations.

The interpretation of some individual principal components will be reported in the following sections.

Table 20. Results (two-significance) of between years F-tests conducted on the first eight principal components scores derived from the basins with the PCA on COV/SV technique. The between years F-tests are performed on the entire basin and on each individual stratum within the basin.

PC	Western basin	Strata	
		0-10m	10m and more
1	***	***	***
2	ns	ns	*
3	*	ns	***
4	***	**	***
5	***	*	**
6	ns	ns	*
7	*	ns	***
8	ns	ns	**

PC	West-Central	Strata		
		0-10m	10m-15m	15m and more
1	*	*	ns	***
2	ns	ns	ns	***
3	**	ns	ns	***
4	***	*	**	***
5	***	*	ns	**
6	***	***	**	***
7	**	ns	ns	***
8	***	ns	ns	***

Legend
- ns non-significant
- * significant at 0.05
- ** significant at 0.01
- *** significant at 0.001

5.2 Status of species and trends in the Western basin

White perch

The mesh size panels showing statistical change in relative abundances are related together (Figure 7a). The significant between years changes of small mesh size panels (32 to 51mm) is followed by significant between years change in large mesh size panels (70mm to 89mm) (Table 13). The mesh size fluctuations show a cohort evolution from 1987 to 1990. The growth in size of a cohort is reflected by the mesh size panels where they are caught. Since the cohort growths in size and then is caught from smaller to larger mesh size with time, it suggests that the cohort is not replaced in later years by new "recruitment" that would be caught by smaller mesh size panels. Also, the cohort does not show large decrease in size (figure 7b) expected due high mortality or catches.

Yellow perch

Yellow perch shows also a cohort pattern across mesh size panels but with some distinctions (Figure 8a). The relative abundances in small mesh size panels are almost the same in 1987 and 1988. Then drops in replacement, detected by the t-tests and the F-tests (Table 12b, 12c and 13), occur in 1989 and 1990. In these later years the past cohorts growth is signaled by increases of the catch in the middle size panels (45 to 57mm). The cohort decreases from density of around 100 in 1987 and 1988 to less than 10 individuals per 45.7 meters of panel in 1990.

Freshwater drum

This fish has small abundances in small mesh size panels during the four years under study (Figure 9a and 9b). This species may be sensitive to catch by middle mesh size panels (51 to 89mm) at their earlier stages of life (Figure 9b). The significant changes appear to occur in 1989 where a drop is observed compared to the two previous years. The "replacement" at these mesh panels is restored in 1990 almost to level observed in 1987 and 1988.

Alewife

This species shows a clear decrease in relative abundance from 1987 to 1989 in mesh size panels from 32 to 57mm (Figure 10a). The decrease is from around 5 to less than 0.5 individuals per panel. The recruitment totally fell down in 1989 and 1990 (Figure 10b).

Walleye

Walleye experienced an increase from 1987 to 1988 in mesh size panels 45 to 70mm (Table 12a, Figure 11a) followed by a decrease in 1989 (Table 12b) and a small increase in 1990 (Table 12c). The changing density levels were around 0.8 individuals/panel in 1987, up to 5 in 1989, down to less than

0.5 in 1989 and finally to near 1.5 in 1990. The shapes of such curves (Figure 11b) suggest that these changes are associated earlier stages of Walleye and larger sizes and more stable.

<u>White sucker</u>

This fish is caught in larger mesh size panels (Figure 12b). The significant difference pointed by the tests is at mesh size 57mm where a drop is observed in 1988 and 1989 compared to 1987 and 1990. But in larger mesh size panels, the density is very stable across the years under study.

<u>Rainbow smelt</u>

Even if large density changes occurred in mesh size 32mm and 38mm, these changes were not significant (Figure 13a). It is at mesh size 51mm that change is signaled where a drop in the density is found in 1988 and 1989 compared to the two other years. The figure 13b is suggesting an increase in small mesh size panels in 1990.

<u>White bass</u>

White bass is a species showing many significant changes in the mesh sizes panels but they are illustrating an evolution of a cohort across mesh size panels (Figures 14a and 14b). The cohort of 1987 decrease from around 1.5 individuals/panels to levels near 0.25 in 1990 in larger mesh size panels. This cohort is not replaced by recruitment between 1988 and 1990.

Rare species

Silver chub is caught in lower mesh size panels and shows significant decrease from 1987 to 1988 around mesh size 51mm. This decrease is more visible in lower mesh sizes where the lowest density is reached in 1989. Spottail shiner shows the same pattern as the previous species where the lower density is also in 1989 at mesh size 32mm. Troutperch shows a decline in 1988 in mesh size 32mm and channel catfish has a little increase of density in the last year of the study.

Trends in the Western basin

A first principal component from a PCA on COV\SV shows a decline in recruitment after 1987 of many species (alewife as the most representative, yellow perch, freshwater drum, white bass and white perch) since these species-mesh variables experience a decrease in replacement of the actual density of 1987 in later years (Figure 30a, Western basin, and Figure 31a). Young/small of those main species are all positively correlated with this principal component. The trend is consistent from 1988 to 1990 in both strata.

The second PC is not associated with significant overall change in the basin but rather associated with change occuring year after year differently among strata, as it is shown in

Figure 31b and 30b. Density of fish is stratified in 1987 and 1990 compared to 1988 and 1989. This component is associated with the relative abundance of the main species. It is specifically positively correlated with middle sizes of white perch and large sizes of white bass and negatively correlated with small/young yellow perch and freshwater drum. This is an example of component which is associated with an interaction of change and habitat.

The PC3 on Figure 30c is associated with the fluctuation of middle mesh size panels (small/young) of Walleye and negatively correlated with small/young of white bass. The pattern of variation by year is consistent in both strata with a increase from 1987 followed by a decrease and finally a recovery in 1990.

PC4 is associated with the fluctuations of middle mesh size panels of white bass where the shift in later years of this species cohort is signaled by these mesh size panels. Other principal components are not specifically associated to main species.

5.3 Status of species and trends in the West-Central basin

White perch

The species shows significant changes in mesh size panels

32 to 89mm. These changes are synchronized in all the described panels (Figure 19a). There is an increase of the density from 1987 to 1988 followed by a decrease in 1989 and an increase in 1990. Figure 29 shows with mesh size panel 45mm the change occuring in the entire lake. In the West-Central basin, the density is clearly dependent of the depth. The change occurred in the deep stratum where the density increased in 1988, drop in 1989 and finally increased in 1990.

<u>Yellow perch</u>

The change of yellow perch density occurred in mesh size panels 32 to 70mm (Figures 20a and 20b). In this basin, the decrease in the recruitment in 1989 and the decrease in importance of the 1987 and 1988 cohorts account for the change.

<u>Freshwater drum</u>

This species showed a significant change in mesh size panel 51mm and t-tests signaled a decrease in mesh size panel 102mm and an increase in mesh size panel 89mm. This species experienced a drop in 1989 (Figure 21b).

<u>Alewife</u>

Occuring in all the mesh size panels in 1987, alewife experienced significant drops in 1988 from small mesh size panels (Figure 22a and Tables 14a and 15). A recruitment is observed in 1989 only for mesh size 32mm. This recruitment seams to be followed in 1990 by an increase in mesh size 38 and 45mm (Figure 22b).

Walleye

Walleye experienced a pattern similar than what occurred in the Western Basin in small and middle mesh size panels. An increase from 1987 to 1988 in mesh size panels 51 to 114mm (Table 14a, Figure 23a) is followed by a decrease in 1989 (Table 14b) and a small increase in 1990 at the largest mesh size panels (Table 14c). In the West-Central basin, the larger sizes of that fish are less stable (Figure 23b) but the density levels are about eight times lower than the other basin.

Rainbow smelt

This species fluctuated in mesh size panels 38 to 102mm. A drop in 1989 followed by an increase in 1990 (Tables 14a,b,c, 15 and figure 24a).

White bass

White bass shows in Figure 25b a cohort evolution through mesh size panels from 1987 to 1990. The significant changes signaled were at mesh 57mm and 64mm where the densities increased and dropped the next two years. The cohort is not replaced in 1988 to 1990 (except for a small peak in 1990 at mesh size 45mm).

Rare species

Spottail shiner shows a decline from 1987 to 1989 with no catch in this basin in 1990. Troutperch declines from 1987 to 1989 but shows increase in 1990. Burdot has very unreliable pattern of fluctuations (Figure 28b).

Trends

The first principal component from a PCA on COV\SV shows a decline in density from 1987 typically correlated with alewife (all mesh sizes) and white bass (small mesh sizes) but also with small/young white perch, yellow perch, freshwater drum and white sucker. This component illustrates also some patterns of change specific with the habitat (stratification, Figure 32a) where the amplitude of variation is greater in the shore stratum compare to the center of the lake (Figure 30a, West-Central basin, Figure 32a). Changes occur in the shore and the deepest strata (Table 20).

The second PC is not associated with significant overall change in the basin but more likely associated with an interaction of change and habitat (Figure 30b, West-Central,

Figure 32b). Year densities recorded in the shore stratum have a different pattern of change compared to the middle and deep strata. This principal component is also positively correlated with some mesh size variables of alewife and white bass and negatively correlated with small/young of yellow perch and freshwater drum.

The PC3 on Figure 30c shows fluctuations associated with white perch from mesh size panels 38 to 64mm and freshwater drum from mesh size panels 57 to 102mm. The PC also reflects an interaction of change and habitat, the pattern of change observed in the shore stratum being different from the other strata of the lake. This PC is associated with an increase in 1988, decrease in 1989 and recovery of 1987 levels in 1990.

The PC4 on Figure 30d illustrates the fluctuation of white perch from mesh size panels 45 to 76mm. The PC also reflects a spatial distribution patterns from shore to the center of the lake but in a special way. As the PC shows increase in 1988, decrease in 1989 and an increase in 1990 (Table 18b), the pattern between strata is not the same. In 1987 shore density is lower than in the middle and deep strata, and the greater density at shore is restored in the three following years.

The PC5 on Figure 30e shows the fluctuation of white bass from mesh size panels 57 to 76mm. It shows the shift of the cohort in larger mesh size panels.

The PC6 on Figure 30f shows the fluctuation of yellow perch from mesh size panels 32 to 70mm, rainbow smelt from mesh size panels 51 to 102 and white perch 76-89mm. High densities are observed in 1987 and 1988 and are followed by two decreases in 1989 and 1990. These fluctuations are consistent in all strata in the basin (Table 20).

Improvement of interpretation is expected with information of the class of age of fish populations. The cohort fluctuations of fish would then be clearly described, not interpreted by partition of the mesh size panels information.

5.4 Estimation methodology with Partial Replacement sampling design

This thesis provided unbiased estimation methodology for sampling with partial replacement. An empirical proof of the unbiasedness of the methodology is given in Appendix 3 where all combinations of samples are generated with very small sample sizes where the double sampling regression theory offers biased estimations of both estimates of change and its variance.

The methodology was developed without the conventional assumption (restriction) of equal variance in the occasion populations. Posten *et al.* (1982) and Posten (1992) discussed the robustness of the student t-test to violation of this assumption. If needed, modification of the estimation methodology can be updated to assume this condition. On the other hand, the works of Mosen *et al.* (1989) and Mosen *et al.* (1992) give some results on the comparison of power analysis of the student t-test (assuming equal variances) and the Satterthwaite t-test. Their tables show clearly that the Satterthwaite approach has only slightly smaller power than the student t approach when the sample sizes are equal and/or the variance are equal but this difference does not hold when the sample sizes are large. However, when the variance are unequal, the Satterthwaite approach is more stable in power than the student t-test where even the size of this test (which is the power at effect size=0) is itself unstable and depend on the degrees of freedom of the largest variance.

I choose to keep the estimation methodology as it has been developed since it endorsed the Satterthwaite characteristics in the estimation.

The estimation methodology appears to be applicable to more cases than the restricted area of sampling with partial replacement. In fact, this methodology includes as specific cases well known cases of inference theory (section 3.1.1 and appendix 2). With two or more sampling occasions, the methodology can manege cases from completely independent samples to completely paired samples in a single inference procedure.

5.5 Evaluation of the sampling design

Evaluation of the sampling design regarding of the special aspect of the partial replacement structure applied in the Lake Erie Program can be done in two parts : a quantitative evaluation and a qualitative evaluation.

The quantitative evaluation is based on the possible improvement of the design, called sampling with partial replacement, compared to the two traditional approaches: a complete replacement of the sample or a sample fixed over time. Without analysis of power of these three approaches, the discussion can be centered on the covariance terms that appear in the sampling variance of the change.

For simplicity, let us study the case of two occasions with the sampling variance derived at equation **(16)** in Chapter 2. This expression was integrated in equation **(84)**, at Chapter 3, in the t variate developed for the t-test. For a fixed change value at the numerator it is possible to study the impact of the denominator terms on the t variate of the three approaches. A decrease of the denominator would increase the t variate.

When there are no matched information (say $n_{tt'}=0$) between two consecutive samples which corresponds to two samples selected from a completely replacement design, the middle term in the denominator becomes null. To improve such situation with a partial replacement design, we would need two samples with matched stations that would provide positive covariance ($s_{x_t x_{t'}}$) between the two occasions in order to decrease the denominator.

When the same sample is kept at the second occasion (fixed over time), the middle term in the denominator is not null. With positive covariance between the two occasions, there is no way that a partial replacement design would improve a fixed over time design. With negative covariance between the two occasions, a partial replacement design would always improve such situation simply because the ($n_{tt'}/n_t\ n_{t'}$) term is always lesser than its value when we have a fixed over time design.

The choice between the three approaches - complete replacement, partial replacement or fixed over time - is a binary decision. If the covariance between the two occasions is positive, then the best choice is the fixed over time option. If the covariance between the two occasions is negative, then the best choice is the complete replacement option.

The final decision of the replacement structure should be based on the objectives of the study.

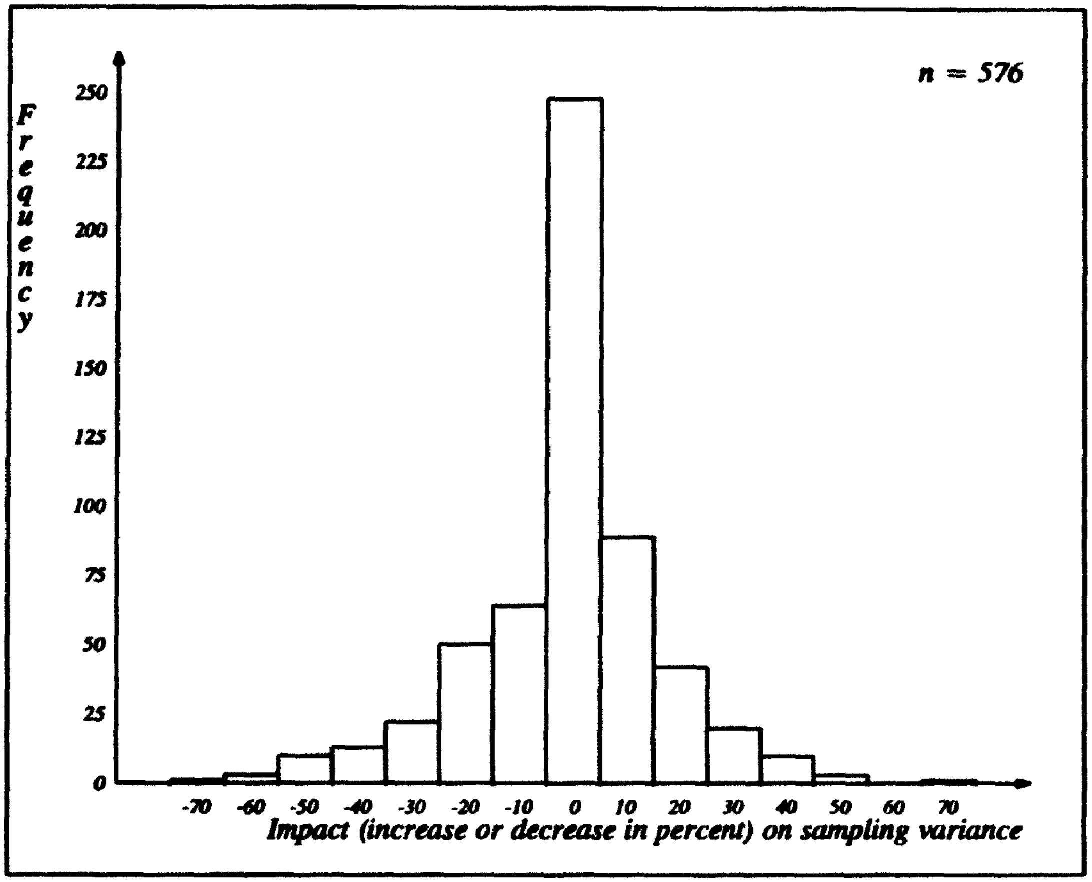
With a major target species, the binary decision could be made after few years of partial replacement selection in order to estimate the covariance between years for that species.

With objectives associated with community assessment, there is not point of reference except the main and secondary species. Appendix 6 provides the covariance between two consecutive years for the eight first abundant species (Table 4) from the log transformed catch. The sign of the covariance is not typically associated across all pairs of years to a species and the sign of the covariance changes sometimes from a stratum to another. White perch, for example, shows negative covariances almost consistently for a given pair of years and a stratum, but the sign change in another stratum and/or another pairs of years.

The impact of the covariance can be estimated directly in the evaluation of the decrease or increase in percent of the denominator of equation **(84)**. Figure 21 illustrates the impact of the covariance for the eight main species in three pairs of years when computable in each stratum. In the case of the Lake Erie Program, it can be shown that the decreases of the sampling variances are balanced by the increases. Without target species and since the covariance is not necessarily predictable or stable (Appendix 6), the actual replacement sampling structure has probably limited the disadvantages of the application of a completely replacement design or a fixed over years design in the same circumstances.

The qualitative evaluation of design is also related to the objectives of the study. From a methodological point of

Figure 33. Impact on the sampling variance of change of the covariance between catch of two consecutive years estimated on the paired catch stations available in a given stratum.



From Appendix 6, there are 576 situations (pair of years in a stratum) available for this illustration. The evaluation of the impact is given in percent by

$$Impact = 100\,\% * \frac{-2 * \left(\frac{n_{tt'}}{n_t n_{t'}} - \frac{1}{N} \right) s_{X_t X_{t'}}}{\left(\frac{1}{n_{t'}} - \frac{1}{N} \right) s_{X_{t'}}^2 + \left(\frac{1}{n_t} - \frac{1}{N} \right) s_{X_t}^2} ;$$

view, a fixed over time design has its intrinsic property to compare the unit with itself. A complete replacement design would provides information not necessarily compatible from a year to another simply because of different samples at the different occasions. On the other hand, the complete replacement design provides information from new catch stations year after year and leads to greater possibility of generalization of the results to the area under study than a fixed sample over time. In both cases, complete replacement and fixed over time options, there is a cost and the partial replacement option reduce the disadvantages of theses cases by providing matched information over time and providing new stations year after year.

Thus, the qualitative evaluation of the design is a matter of validity in the comparison and validity in the generalization of the results and should be the first criteria in the choice of the replacement structure. The actual values of the covariance between two years of the variables of interest is a second step to improve the number of paired catch stations to keep in order to achieve the objectives of the study.

APPENDIX 1.

Examples of the computation of the maximum number of degrees of freedom (equation **(93)**) of the t variate (equation **(84)**) in a sampling design with partial replacement and its relation with the computation of the number of degrees of freedom of the t-test (equation **(89)**) and the paired t-test (equation **(92)**) .

Let suppose that 4 units per occasion are visited to get the X observations. For the convenience and the simplicity of the presentation, let two X values in the same column be paired, otherwise not paired. The five situations described make $n_{tt'}$, the number of paired units, varying from 4 to 0.

Situations $n_t=n_{t'}=4$	n_{obs} $(n_t+n_{t'})$	k	n_{paired} $(n_{tt'})$	*if* $n_{paired}>1$ $(n_{paired}-1)$ *otherwise 0*	ν PR_{max}	ν t-test	ν paired t-test
occasion t : X X X X occasion t': X X X X	8	2	4	3	3	-	3
occasion t : X X X X occasion t': X X X X	8	2	3	2	4	-	-
occasion t : X X X X occasion t': X X X X	8	2	2	1	5	-	-
occasion t : X X X X occasion t': X X X X	8	2	1	0	6	-	-
occasion t : X X X X occasion t': X X X X	8	2	0	0	6	6	-

APPENDIX 2.

Numerical examples that show the comparison between traditional analysis of variance and the method of inference developed for multiple occasions presented at section 3.1.2.

CASE 1 : Oneway analysis of variance for completely independent occasions, equal sample sizes and equal occasion variances

DATA	no paired units	mean	n	sample variances and covariances		
occasion 1 :	1 2 3 - - - - - -	2.0	3	1.0	-	-
occasion 2 :	- - - 4 6 5 - - -	5.0	3	-	1.0	-
occasion 3 :	- - - - - - 8 7 9	8.0	3	-	-	1.0

According to equations **(20)**, **(23)** and **(100)**, and if we ignore (1 / *N*) :

Variance between occasions	**(20)**	=	9.0000
Sampling variance	**(23)**	=	0.3333
F ratio	**(100)**	=	27.0000
Degrees of freedom **(100)**			
numerator (k-1)		=	2
denominator **(99)**		=	6

Traditional ONEWAY Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio
Between Occasions	2	54.000	27.000	27.0
Within Groups	6	6.000	1.000	
Total	8	60.000		

(continued)

APPENDIX 2. (continued)

CASE 2 : Two-way analysis of variance for completely paired occasions, equal sample sizes and equal occasion variances

DATA Units	1 2 3	mean	n	sample variances and covariances		
occasion 1 :	1 2 3	2.0	3	1.0	0.5	0.5
occasion 2 :	4 6 5	5.0	3	0.5	1.0	-0.5
occasion 3 :	8 7 9	8.0	3	0.5	-0.5	1.0

According to equations **(20)**, **(23)** and **(100)**, and if we ignore (1 / N) :

Variance between occasions	**(20)**	=	9.0000
Sampling variance	**(23)**	=	0.2778
F ratio	**(100)**	=	32.4000
Degrees of freedom of **(100)**			
numerator (k-1)		=	2
denominator **(99)**		=	4

Traditional TWO-WAY Analysis of Variance, one replicate per cell, using the Interaction term as the Mean Squared Error.

Source	D.F.	Sum of Squares	Mean Squares	F Ratio
Between Occasions	2	54.000	27.000	32.4
Between Units	2	2.667	1.333	1.6
Two-way Interaction (MSE) Occasions * Units	4	3.333	0.833	
Total	8	60.000		

APPENDIX 3.

Empirical proof of unbiasedness of the estimator of change **(9)** and its sampling variance **(16)** in a simple population measured at two occasions.

Let a population of N = 5 units be sampled the first occasion with n_1 = 3, n_{12} = 2 units are kept and one (n_2 - n_{12}) unit is selected in the two (N - n_1) remaining units in the population in order to complete the second sample to n_2 = 3.

The sampling sequence over all possible samples is shown in the next pages. Sixty different samples can be generated with the sizes of population and samples chosen. Each sample is presented in three lines: the first line are the values of the selected units at the first drawing. The second line are the values of the selected units at the second occasion with the partial replacement sampling design. At the end of these lines, estimations of the means, the variances and the covariance are provided. The third line applied the computation of the measure of change and its estimated sampling variance. The last information is the actual deviation of the estimate of change to the true change.

no	U_1	U_2	U_3	U_4	U_5	Mean1 / Mean2	Variance1 / Variance2	Covariance	(9) $\bar{d}_{21}$	(16) $v(\bar{d}_{21})$	$\bar{d}_{21}-\Delta_{21}$
1	0.75	0.96	1.24	-----	-----	0.9832	0.0599				
	0.84	1.23	-----	1.09	-----	1.0526	0.0376	0.0406			
									0.0694	0.0112	0.0881
2	0.75	0.96	1.24	-----	-----	0.9832	0.0599				
	0.84	1.23	-----	-----	1.63	1.2324	0.1527	0.0406			
									0.2492	0.0265	0.2680

(continued)

(Appendix 3 continued)

3	0.75	0.96	1.24	-----	-----	0.9832	0.0599				
	0.84	-----	1.74	1.09	-----	1.2229	0.2140	0.2182			
									0.2397	0.0268	0.2585
4	0.75	0.96	1.24	-----	-----	0.9832	0.0599				
	0.84	-----	1.74	-----	1.63	1.4028	0.2372	0.2182			
									0.4196	0.0299	0.4383
5	0.75	0.96	1.24	-----	-----	0.9832	0.0599				
	-----	1.23	1.74	1.09	-----	1.3507	0.1178	0.0706			
									0.3675	0.0205	0.3863
6	0.75	0.96	1.24	-----	-----	0.9832	0.0599				
	-----	1.23	1.74	-----	1.63	1.5305	0.0721	0.0706			
									0.5473	0.0145	0.5661
7	0.75	0.96	-----	2.23	-----	1.3131	0.6384				
	0.84	1.23	1.74	-----	-----	1.2700	0.2013	0.0406			
									-0.0431	0.1102	-0.0243
8	0.75	0.96	-----	2.23	-----	1.3131	0.6384				
	0.84	1.23	-----	-----	1.63	1.2324	0.1527	0.0406			
									-0.0807	0.1037	-0.0619
9	0.75	0.96	-----	2.23	-----	1.3131	0.6384				
	0.84	-----	1.74	1.09	-----	1.2229	0.2140	0.1788			
									-0.0902	0.1057	-0.0714
10	0.75	0.96	-----	2.23	-----	1.3131	0.6384				
	0.84	-----	-----	1.09	1.63	1.1853	0.1601	0.1788			
									-0.1278	0.0985	-0.1090
11	0.75	0.96	-----	2.23	-----	1.3131	0.6384				
	-----	1.23	1.74	1.09	-----	1.3507	0.1178	-0.0894			
									0.0376	0.1048	0.0564
12	0.75	0.96	-----	2.23	-----	1.3131	0.6384				
	-----	1.23	-----	1.09	1.63	1.3131	0.0783	-0.0894			
									0.0000	0.0995	0.0188

(continued)

(Appendix 3 continued)

13	0.75	0.96	-----	-----	1.44	1.0501	0.1244				
	0.84	1.23	1.74	-----	-----	1.2700	0.2013	0.0406			
									0.2199	0.0416	0.2387
14	0.75	0.96	-----	-----	1.44	1.0501	0.1244				
	0.84	1.23	-----	1.09	-----	1.0526	0.0376	0.0406			
									0.0025	0.0198	0.0213
15	0.75	0.96	-----	-----	1.44	1.0501	0.1244				
	0.84	-----	1.74	-----	1.63	1 4028	0.2372	0.2691			
									0.3527	0.0363	0.3714
16	0.75	0.96	-----	-----	1.44	1.0501	0.1244				
	0.84	-----	-----	1.09	1.63	1.1853	0.1601	0.2691			
									0.1353	0.0260	0.1540
17	0.75	0.96	-----	-----	1.44	1.0501	0.1244				
	-----	1.23	1.74	-----	1.63	1.5305	0.0721	0.0949			
									0.4805	0.0220	0.4992
18	0.75	0.96	-----	-----	1.44	1.0501	0.1244				
	-----	1.23	-----	1.09	1.63	1.3131	0.0783	0.0949			
									0.2630	0.0228	0.2818
19	0.75	-----	1.24	2.23	-----	1.4052	0.5668				
	0.84	1.23	1.74	-----	-----	1.2700	0.2013	0.2182			
									-0.1351	0.0927	-0.1164
20	0.75	-----	1.24	2.23	-----	1.4052	0.5668				
	0.84	-----	1.74	-----	1.63	1.4028	0.2372	0.2182			
									-0.0024	0.0975	0.0164
21	0.75	-----	1.24	2.23	-----	1.4052	0.5668				
	0.84	1.23	-----	1.09	-----	1.0526	0.0376	0.1788			
									-0.3526	0.0726	-0.3338
22	0.75	-----	1.24	2.23	-----	1.4052	0.5668				
	0.84	-----	-----	1.09	1.63	1.1853	0.1601	0.1788			
									-0.2198	0.0890	-0.2011

(continued)

(Appendix 3 continued)

23	0.75	-----	1.24	2.23	-----	1.4052	0.5668				
	-----	1.23	1.74	1.09	-----	1.3507	0.1178	-0.3228			
									-0.0544	0.1056	-0.0357
24	0.75	-----	1.24	2.23	-----	1.4052	0.5668				
	-----	-----	1.74	1.09	1.63	1.4835	0.1215	-0.3228			
									0.0783	0.1061	0.0971
25	0.75	-----	1.24	-----	1.44	1.1421	0.1254				
	0.84	1.23	1.74	-----	-----	1.2700	0.2013	0.2182			
									0.1279	0.0339	0.1466
26	0.75	-----	1.24	-----	1.44	1.1421	0.1254				
	0.84	-----	1.74	1.09	-----	1.2229	0.2140	0.2182			
									0.0808	0.0356	0.0996
27	0.75	-----	1.24	-----	1.44	1.1421	0.1254				
	0.84	1.23	-----	-----	1.63	1.2324	0.1527	0.2691			
									0.0903	0.0251	0.1090
28	0.75	-----	1.24	-----	1.44	1.1421	0.1254				
	0.84	-----	-----	1.09	1.63	1.1853	0.1601	0.2691			
									0.0432	0.0261	0.0620
29	0.75	-----	1.24	-----	1.44	1.1421	0.1254				
	-----	1.23	1.74	-----	1.63	1.5305	0.0721	-0.0113			
									0.3884	0.0268	0.4072
30	0.75	-----	1.24	-----	1.44	1.1421	0.1254				
	-----	-----	1.74	1.09	1.63	1.4835	0.1215	-0.0113			
									0.3413	0.0334	0.3601
31	0.75	-----	-----	2.23	1.44	1.4720	0.5467				
	0.84	1.23	-----	1.09	-----	1.0526	0.0376	0.1788			
									-0.4194	0.0699	-0.4007

(continued)

(Appendix 3 continued)

32	0.75	-----	-----	2.23	1.44	1.'720	0.5467				
	0.84	-----	1.74	1.09	-----	1.2229	0.2140	0.1788			
									-0.2491	0.0935	-0.2303
33	0.75	-----	-----	2.23	1.44	1.4720	0.5467				
	0.84	1.23	-----	-----	1.63	1.2324	0.1527	0.2691			
									-0.2396	0.0813	-0.2209
34	0.75	-----	-----	2.23	1.44	1.4720	0.5467				
	0.84	-----	1.74	-----	1.63	1.4028	0.2372	0.2691			
									-0.0693	0.0926	-0.0505
35	0.75	-----	-----	2.23	1.44	1.4720	0.5467				
	-----	1.23	-----	1.09	1.63	1.3131	0.0783	-0.2128			
									-0.1589	0.0928	-0.1402
36	0.75	-----	-----	2.23	1.44	1.4720	0.5467				
	-----	-----	1.74	1.09	1.63	1.4835	0.1215	-0.2128			
									0.0114	0.0986	0.0302
37	-----	0.96	1.24	2.23	-----	1.4757	0.4430				
	0.84	1.23	1.74	-----	-----	1.2700	0.2013	0.0706			
									-0.2057	0.0828	-0.1869
38	-----	0.96	1.24	2.23	-----	1.4757	0.4430				
	-----	1.23	1.74	-----	1.63	1.5305	0.0721	0.0706			
									0.0548	0.0655	0.0736
39	-----	0.96	1.24	2.23	-----	1.4757	0.4430				
	0.84	1.23	-----	1.09	-----	1.0526	0.0376	-0.0894			
									-0.4231	0.0681	-0.4044
40	-----	0.96	1.24	2.23	-----	1.4757	0.4430				
	-----	1.23	-----	1.09	1.63	1.3131	0.0783	-0.0894			
									-0.1626	0.0735	-0.1439

(continued)

(Appendix 3 continued)

41	-----	0.96	1.24	2.23	-----	1.4757	0.4430				
	0.84	-----	1.74	1.09	-----	1.2229	0.2140	-0.3228			
									-0.2528	0.1020	-0.2340
42	-----	0.96	1.24	2.23	-----	1.4757	0.4430				
	-----	-----	1.74	1.09	1.63	1.4835	0.1215	-0.3228			
									0.0077	0.0896	0.0265
43	-----	0.96	1.24	-----	1.44	1.2127	0.0573				
	0.84	1.23	1.74	-----	-----	1.2700	0.2013	0.0706			
									0.0573	0.0313	0.0761
44	-----	0.96	1.24	-----	1.44	1.2127	0.0573				
	-----	1.23	1.74	1.09	-----	1.3507	0.1178	0.0706			
									0.1380	0.0202	0.1568
45	-----	0.96	1.24	-----	1.44	1.2127	0.0573				
	0.84	1.23	-----	-----	1.63	1.2324	0.1527	0.0949			
									0.0197	0.0238	0.0385
46	-----	0.96	1.24	-----	1.44	1.2127	0.0573				
	-----	1.23	-----	1.09	1.63	1.3131	0.0783	0.0949			
									0.1004	0.0139	0.1191
47	-----	0.96	1.24	-----	1.44	1.2127	0.0573				
	0.84	-----	1.74	-----	1.63	1.4028	0.2372	-0.0113			
									0.1901	0.0398	0.2088
48	-----	0.96	1.24	-----	1.44	1.2127	0.0573				
	-----	-----	1.74	1.09	1.63	1.4835	0.1215	-0.0113			
									0.2707	0.0244	0.2895
49	-----	0.96	-----	2.23	1.44	1.5426	0.4087				
	0.84	1.23	-----	1.09	-----	1.0526	0.0376	-0.0894			
									-0.4900	0.0635	-0.4713

(continued)

(Appendix 3 continued)

50	-----	0.96	-----	2.23	1.44	1.5426	0.4087				
	-----	1.23	1.74	1.09	-----	1.3507	0.1178	-0.0894			
									-0.1919	0.0742	-0.1731
51	-----	0.96	-----	2.23	1.44	1.5426	0.4087				
	0.84	1.23	-----	-----	1.63	1.2324	0.1527	0.0949			
									-0.3102	0.0706	-0.2914
52	-----	0.96	-----	2.23	1.44	1.5426	0.4087				
	-----	1.23	1.74	-----	1.63	1.5305	0.0721	0.0949			
									-0.0121	0.0599	0.0067
53	-----	0.96	-----	2.23	1.44	1.5426	0.4087				
	0.84	-----	-----	1.09	1.63	1.1853	0.1601	-0.2128			
									-0.3573	0.0853	-0.3385
54	-----	0.96	-----	2.23	1.44	1.5426	0.4087				
	-----	-----	1.74	1.09	1.63	1.4835	0.1215	-0.2128			
									-0.0592	0.0802	-0.0404
55	-----	-----	1.24	2.23	1.44	1.6347	0.2737				
	0.84	-----	1.74	1.09	-----	1.2229	0.2140	-0.3228			
									-0.4117	0.0794	-0.3930
56	-----	-----	1.24	2.23	1.44	1.6347	0.2737				
	-----	1.23	1.74	1.09	-----	1.3507	0.1178	-0.3228			
									-0.2840	0.0665	-0.2652
57	-----	-----	1.24	2.23	1.44	1.6347	0.2737				
	0.84	-----	1.74	-----	1.63	1.4028	0.2372	-0.0113			
									-0.2319	0.0686	-0.2131
58	-----	-----	1.24	2.23	1.44	1.6347	0.2737				
	-----	1.23	1.74	-----	1.63	1.5305	0.0721	-0.0113			
									-0.1041	0.0466	-0.0854

(continued)

(Appendix 3 continued)

59	-----	-----	1.24	2.23	1.44	1.6347	0.2737					
	0.84	-----	-----	1.09	1.63	1.1853	0.1601	-0.2128				
									-0.4493	0.0673	-0.4306	
60	-----	-----	1.24	2.23	1.44	1.6347	0.2737					
	-----	1.23	-----	1.09	1.63	1.3131	0.0783	-0.2128				
									-0.3216	0.0564	-0.3028	

Expectation (mean over all samples)

$E(\bar{d}_{21})$	-0.0138		
$E(v(\bar{d}_{21}))$		0.0608	
$E(\bar{d}_{21}-\Delta_{21})$			0.0000
$E(\bar{d}_{21}-\Delta_{21})^2=V(\bar{d}_{21})$			0.0608

In the population:

U_1	U_2	U_3	U_4	U_5	
0.75	0.96	1.24	2.23	1.44	1.3231 =Population mean 1
0.84	1.23	1.74	1.09	1.63	1.3044 =Population mean 2
					-0.0188 = Δ_{21}

Note that the $E(\bar{d}_{21})$ is equal to the Δ_{21} and then is unbiased. The $E(v(\bar{d}_{21}))$ is equal to the mean of the squared deviations of the estimate from the true value and then is also unbiased.

Appendix 4. Loading coefficients for the first eight PC derived from the Principal Component Analysis, on COV/SV with the log transformed relative abundances of species-mesh variables in the Western basin.

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
WPer	PC1	0.127	0.142	0.121	0.110	0.047	0.052	-0.068	-0.060	-0.075	0.010	0.045	0.073
	PC2	0.103	0.122	0.150	0.174	0.180	0.167	0.182	0.194	0.189	0.194	0.159	0.076
	PC3	-0.060	-0.090	-0.072	-0.042	-0.036	-0.057	0.056	0.020	-0.043	-0.023	-0.013	-0.034
	PC4	0.118	0.069	0.093	0.113	0.068	0.049	0.090	0.077	0.058	0.017	0.099	0.042
	PC5	-0.081	-0.075	-0.032	-0.035	0.012	0.010	0.021	0.040	0.056	0.045	-0.045	-0.028
	PC6	-0.003	-0.008	-0.036	-0.032	-0.042	-0.049	-0.096	-0.090	-0.090	-0.053	-0.043	-0.076
	PC7	-0.014	-0.051	-0.046	-0.025	0.016	0.053	0.061	0.076	0.091	0.071	-0.020	0.061
	PC8	0.030	0.035	0.059	0.042	0.043	0.034	0.025	0.025	0.042	0.052	0.013	-0.006
YPer	PC1	0.189	0.165	0.155	0.110	0.084	0.065	0.011	0.054	0.078	0.020	0.075	0.041
	PC2	-0.161	-0.136	-0.150	-0.142	-0.137	-0.077	-0.071	-0.083	-0.044	0.012	0.002	0.035
	PC3	-0.008	-0.001	0.009	-0.020	0.002	0.030	0.018	-0.072	-0.053	-0.022	0.023	0.148
	PC4	0.075	0.099	0.110	0.060	0.146	0.078	0.076	0.031	-0.010	-0.013	-0.087	-0.103
	PC5	-0.127	-0.066	-0.168	-0.104	-0.070	-0.010	0.016	-0.001	0.034	0.009	-0.017	-0.080
	PC6	0.050	0.064	0.141	0.078	0.091	0.069	0.006	0.010	0.011	0.102	0.002	0.036
	PC7	-0.055	-0.045	-0.025	0.008	0.109	0.162	0.066	0.099	0.050	0.043	0.058	0.049
	PC8	0.077	0.130	0.147	0.126	0.069	0.060	0.019	-0.004	0.120	0.115	-0.027	-0.013
FreD	PC1	0.038	0.070	0.082	0.140	0.126	0.129	0.140	0.136	0.098	0.108	0.067	0.087
	PC2	-0.042	-0.028	-0.037	-0.134	-0.159	-0.112	-0.091	-0.085	-0.074	-0.001	0.025	-0.018
	PC3	0.075	-0.048	0.031	-0.047	-0.023	-0.020	-0.015	-0.010	0.032	0.038	0.034	0.021
	PC4	-0.017	-0.013	0.071	0.058	0.084	0.087	0.029	0.016	0.055	0.065	0.085	0.068
	PC5	0.087	0.112	0.181	0.101	0.112	0.135	0.148	0.154	0.158	0.144	0.135	0.130
	PC6	0.028	-0.078	0.025	0.013	-0.020	-0.012	-0.067	-0.045	-0.060	-0.113	-0.105	-0.132
	PC7	0.010	0.020	-0.043	-0.025	-0.006	-0.031	-0.046	-0.068	-0.069	-0.053	-0.054	0.006
	PC8	-0.063	0.051	-0.074	-0.028	-0.026	-0.010	-0.029	-0.045	-0.012	-0.068	-0.083	-0.060
Alew	PC1	0.213	0.221	0.166	0.223	0.136	0.027	0.086	0.103	0.019	0.132	0.138	0.086
	PC2	0.059	0.082	0.085	0.120	0.118	0.038	0.029	0.019	-0.017	0.056	0.062	0.029
	PC3	-0.091	-0.089	-0.022	-0.065	-0.088	-0.034	-0.079	-0.089	0.002	-0.133	-0.143	-0.079
	PC4	-0.047	-0.095	-0.101	-0.127	-0.092	-0.045	0.016	0.005	0.035	0.017	0.016	0.016
	PC5	-0.043	-0.085	-0.107	-0.089	-0.079	-0.085	0.019	0.009	-0.011	0.014	0.010	0.019
	PC6	-0.017	0.047	-0.007	0.036	-0.035	-0.045	-0.047	0.021	0.002	-0.042	-0.035	-0.047
	PC7	-0.013	-0.089	-0.071	-0.045	-0.046	-0.209	0.048	0.074	-0.006	0.084	0.091	0.048
	PC8	-0.030	-0.072	-0.090	-0.044	-0.108	-0.108	-0.031	0.022	0.017	-0.025	-0.020	-0.031

(continued)

(Appendix 4 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Wall	PC1	0.160	0.103	0.153	0.098	0.098	0.100	0.087	0.123	0.037	0.021	0.013	-0.000
	PC2	0.034	0.057	0.030	0.008	-0.014	0.020	0.003	0.052	0.019	0.097	0.069	0.097
	PC3	0.041	0.022	0.019	0.199	0.238	0.279	0.233	0.178	0.148	0.096	0.088	0.046
	PC4	-0.065	-0.083	-0.052	0.134	0.223	0.246	0.154	0.102	0.080	0.048	0.020	-0.012
	PC5	0.029	0.006	-0.001	-0.044	-0.035	-0.049	0.040	0.034	0.054	0.090	0.127	0.072
	PC6	-0.011	-0.047	0.032	-0.094	-0.107	-0.067	-0.032	0.042	0.046	0.088	0.077	0.041
	PC7	0.056	0.066	-0.076	-0.091	-0.070	-0.189	-0.020	-0.039	0.051	0.087	0.136	0.077
	PC8	-0.065	0.085	-0.055	-0.095	0.002	0.043	-0.027	-0.009	-0.093	0.006	-0.085	0.005
WSuc	PC1	0.019			0.061	0.093	0.128	0.105	0.128	0.081	0.076	0.031	-0.049
	PC2	-0.017			0.015	-0.003	-0.005	-0.032	-0.032	0.002	0.010	0.062	0.048
	PC3	-0.009			0.086	0.008	-0.036	0.004	0.001	-0.018	0.023	0.044	0.017
	PC4	0.024			-0.093	-0.092	-0.056	-0.025	-0.028	0.096	0.063	-0.006	0.090
	PC5	-0.004			0.016	0.066	0.051	0.041	0.051	0.117	0.122	0.162	-0.045
	PC6	0.001			-0.014	-0.005	-0.004	0.060	0.055	0.037	0.043	0.025	-0.049
	PC7	0.013			0.015	0.080	0.062	0.060	0.051	0.050	0.085	0.089	0.062
	PC8	0.042			0.032	0.130	0.068	0.036	0.063	-0.009	-0.009	-0.011	-0.004
RaSm	PC1	-0.011	-0.015	0.002	-0.014	-0.029	-0.020	-0.009	-0.018	0.039	-0.017	0.009	
	PC2	-0.054	-0.054	-0.029	-0.063	-0.018	-0.082	-0.067	-0.028	-0.028	0.004	-0.037	
	PC3	0.011	-0.001	0.014	-0.035	-0.022	-0.052	-0.031	-0.030	-0.007	-0.012	-0.027	
	PC4	-0.000	-0.039	-0.025	-0.061	-0.067	-0.076	-0.064	-0.050	0.001	-0.025	-0.021	
	PC5	0.111	0.047	0.079	0.033	-0.004	-0.010	0.068	-0.032	0.018	0.019	-0.013	
	PC6	-0.014	-0.025	-0.044	-0.057	-0.088	-0.000	0.010	0.001	0.027	-0.034	0.025	
	PC7	0.052	0.003	-0.031	-0.041	-0.056	-0.028	0.016	-0.010	0.025	-0.000	-0.004	
	PC8	-0.071	-0.039	-0.080	-0.051	0.102	-0.01[illegible]	-0.025	0.006	0.025	-0.015	0.019	
WBas	PC1	0.068	0.077	0.154	-0.028	-0.019	-0.009	-0.045	-0.015	-0.041	-0.062	0.030	-0.030
	PC2	0.033	0.036	0.012	0.051	0.049	0.089	0.094	0.107	0.103	0.070	0.068	0.048
	PC3	-0.084	-0.108	-0.142	0.013	0.050	0.049	0.059	0.070	-0.033	-0.001	0.039	0.005
	PC4	0.029	0.013	0.010	0.072	0.163	0.224	0.198	0.182	0.085	0.007	-0.017	0.059
	PC5	0.061	0.053	-0.001	-0.117	-0.125	-0.098	-0.153	-0.120	-0.077	-0.010	-0.035	-0.051
	PC6	0.1[illegible]1	0.105	-0.011	-0.023	-0.060	0.048	-0.046	0.065	-0.003	0.026	-0.074	0.014
	PC7	-0.049	-0.050	0.092	-0.034	-0.009	-0.006	0.041	0.031	0.204	0.106	0.050	0.029
	PC8	0.044	0.023	0.001	-0.028	0.036	0.038	0.022	0.037	-0.002	-0.051	0.080	-0.004

(continued)

(Appendix 4 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
SiCh	PC1	0.056	0.082	0.097	0.082	-0.037							0.069
	PC2	0.028	0.014	0.010	-0.011	0.010							0.055
	PC3	0.124	0.131	0.122	0.133	-0.025							0.171
	PC4	-0.127	-0.113	-0.081	-0.070	-0.039							-0.145
	PC5	0.019	-0.021	-0.042	-0.028	-0.036							-0.053
	PC6	-0.038	0.058	0.010	0.039	0.012							0.045
	PC7	0.001	0.094	0.040	0.032	0.046							0.048
	PC8	0.131	0.103	0.104	0.023	-0.022							-0.035
SpSh	PC1	0.053	-0.006	-0.030				0.015			0.015		
	PC2	0.076	0.055	0.048				0.035			0.035		
	PC3	-0.076	-0.032	0.005				0.030			0.030		
	PC4	-0.015	-0.057	0.059				-0.042			-0.042		
	PC5	-0.097	-0.056	-0.051				0.025			0.025		
	PC6	-0.059	-0.031	0.014				-0.007			-0.007		
	PC7	-0.131	-0.159	0.029				0.085			0.085		
	PC8	-0.084	-0.103	-0.004				0.152			0.152		
Trpe	PC1	0.040	-0.003										
	PC2	-0.059	0.059										
	PC3	-0.095	-0.015										
	PC4	-0.036	0.036										
	PC5	0.005	0.074										
	PC6	-0.014	0.239										
	PC7	0.015	-0.141										
	PC8	0.015	0.078										
GSha	PC1					0.075	-0.032		0.086	0.083	0.028	-0.033	-0.001
	PC2					0.020	0.080		0.029	0.072	0.062	0.118	0.131
	PC3					-0.067	-0.019		-0.079	-0.107	-0.088	-0.039	-0.058
	PC4					0.031	0.001		0.016	0.026	-0.036	-0.028	-0.022
	PC5					-0.012	0.075		0.019	0.063	0.001	0.080	0.050
	PC6					0.002	0.017		-0.047	-0.020	-0.043	-0.030	-0.014
	PC7					0.041	0.034		0.048	0.076	0.002	-0.026	0.108
	PC8					0.016	-0.059		-0.031	-0.055	-0.086	-0.021	0.009

(continued)

(Appendix 4 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
ChCa	PC1			0.015	0.051	0.049	0.060	-0.007	-0.035	0.061	0.054	-0.019	-0.010
	PC2			0.035	0.065	0.060	-0.037	0.034	0.072	0.042	0.098	0.127	-0.004
	PC3			0.030	0.153	0.170	-0.005	0.007	-0.005	-0.049	0.031	-0.015	0.011
	PC4			-0.042	-0.117	-0.134	0.033	-0.010	0.015	-0.012	-0.059	0.013	0.033
	PC5			0.025	-0.024	0.061	0.055	0.080	0.110	0.074	0.090	0.078	0.074
	PC6			-0.007	0.049	-0.053	0.028	-0.119	-0.037	-0.010	0.054	-0.039	-0.063
	PC7			0.085	0.068	-0.021	0.019	-0.050	0.029	0.112	-0.012	-0.164	0.006
	PC8			0.152	-0.052	0.028	0.023	0.124	-0.076	0.050	-0.045	0.035	-0.037
SBas	PC1						-0.045	-0.023	-0.031	-0.056	-0.046	-0.052	-0.038
	PC2						0.092	0.076	0.066	0.099	0.115	0.106	0.107
	PC3						0.002	0.002	-0.018	0.002	-0.014	-0.004	-0.022
	PC4						0.045	0.026	0.002	0.025	0.073	0.036	0.015
	PC5						0.027	0.077	0.073	0.058	0.042	0.054	0.091
	PC6						0.029	0.181	0.188	0.034	0.199	0.172	0.149
	PC7						0.064	-0.063	-0.059	0.060	-0.053	-0.037	-0.060
	PC8						-0.056	0.010	0.031	-0.082	0.028	-0.009	-0.005
RBas	PC1	-0.002		-0.025	0.098	-0.002	0.019	0.048	-0.021	-0.016	0.030		
	PC2	-0.012		-0.017	0.054	0.047	0.100	0.039	0.032	0.085	0.058		
	PC3	0.007		-0.009	-0.111	-0.046	0.045	0.153	0.039	-0.038	-0.048		
	PC4	-0.022		-0.028	0.006	-0.015	-0.096	-0.102	0.088	0.008	-0.060		
	PC5	0.055		-0.020	-0.006	-0.012	-0.010	-0.033	-0.071	0.059	-0.080		
	PC6	-0.051		0.018	0.000	0.035	0.161	0.030	-0.016	0.010	-0.049		
	PC7	-0.015		0.009	0.074	0.025	-0.137	0.030	0.041	0.062	-0.208		
	PC8	-0.052		-0.014	0.004	-0.018	0.028	-0.051	0.002	-0.084	-0.114		
Lota	PC1									-0.001			-0.021
	PC2									0.016			-0.025
	PC3									0.042			-0.009
	PC4									0.073			-0.028
	PC5									-0.066			-0.015
	PC6									-0.031			0.009
	PC7									0.002			0.027
	PC8									0.027			0.002

(continued)

(Appendix 4 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
NRSu	PC1					0.008	0.004		0.030	0.030	-0.005	-0.033	0.008
	PC2					-0.014	-0.013		0.058	0.028	0.056	0.097	-0.014
	PC3					0.080	0.070		-0.048	0.003	0.018	-0.033	0.080
	PC4					0.033	0.033		-0.060	-0.007	0.034	0.007	0.033
	PC5					0.182	0.167		-0.080	-0.071	0.178	0.076	0.182
	PC6					-0.038	-0.041		-0.049	-0.030	0.100	0.146	-0.038
	PC7					-0.016	-0.024		-0.208	-0.140	-0.038	-0.038	-0.016
	PC8					-0.153	-0.149		-0.114	-0.051	-0.074	-0.003	-0.153
LaWh	PC1										-0.019		
	PC2										0.006		
	PC3										-0.025		
	PC4										-0.004		
	PC5										-0.031		
	PC6										-0.016		
	PC7										0.042		
	PC8										0.027		
Coho	PC1			-0.003									
	PC2			0.059									
	PC3			-0.015									
	PC4			0.036									
	PC5			0.074									
	PC6			0.239									
	PC7			-0.141									
	PC8			0.078									
Ston	PC1		-0.030			-0.013	-0.016		0.014				
	PC2		0.048			0.071	0.041		0.013				
	PC3		0.005			-0.001	0.014		0.016				
	PC4		0.059			-0.016	-0.059		-0.012				
	PC5		-0.051			0.112	0.084		0.012				
	PC6		0.014			0.062	-0.151		0.034				
	PC7		0.029			-0.176	-0.108		0.040				
	PC8		-0.004			0.205	0.212		-0.020				

(continued)

(Appendix 4 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
EShi	PC1	0.098											
	PC2	0.054											
	PC3	-0.111											
	PC4	0.006											
	PC5	-0.006											
	PC6	0.000											
	PC7	0.074											
	PC8	0.004											
Quil	PC1					-0.025			-0.016				
	PC2					0.000			0.041				
	PC3					-0.004			0.014				
	PC4					-0.006			-0.059				
	PC5					-0.038			0.084				
	PC6					0.006			-0.151				
	PC7					0.037			-0.108				
	PC8					0.014			0.212				
BBul	PC1				0.069		-0.014		-0.016				
	PC2				0.055		0.049		0.041				
	PC3				0.171		-0.009		0.014				
	PC4				-0.145		0.016		-0.059				
	PC5				-0.053		0.079		0.084				
	PC6				0.045		0.204		-0.151				
	PC7				0.048		-0.113		-0.108				
	PC8				-0.035		0.043		0.212				
Bowf	PC1										-0.023		
	PC2										0.075		
	PC3										-0.032		
	PC4										-0.002		
	PC5										0.023		
	PC6										-0.021		
	PC7										0.055		
	PC8										-0.018		

(continued)

(Appendix 4 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
GoRe	PC1									-0.016			-0.001
	PC2									0.041			0.057
	PC3									0.014			0.033
	PC4									-0.059			-0.076
	PC5									0.084			0.082
	PC6									-0.151			-0.119
	PC7									-0.108			-0.018
	PC8									0.212			0.273
TaMa	PC1				0.001	-0.016		0.030					
	PC2				-0.044	0.041		0.058					
	PC3				-0.010	0.014		-0.048					
	PC4				-0.019	-0.059		-0.060					
	PC5				0.069	0.084		-0.080					
	PC6				0.057	-0.151		-0.049					
	PC7				0.051	-0.108		-0.208					
	PC8				0.009	0.212		-0.114					
YBul	PC1				-0.011		-0.003						
	PC2				0.027		0.059						
	PC3				-0.014		-0.015						
	PC4				0.009		0.036						
	PC5				0.075		0.074						
	PC6				0.214		0.239						
	PC7				-0.082		-0.141						
	PC8				0.065		0.078						
Carp	PC1										0.069	0.069	-0.004
	PC2										0.055	0.055	0.046
	PC3										0.171	0.171	0.019
	PC4										-0.145	-0.145	0.079
	PC5										-0.053	-0.053	-0.044
	PC6										0.045	0.045	-0.048
	PC7										0.048	0.048	-0.005
	PC8										-0.035	-0.035	0.015

(continued)

(Append. . 4 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
LaTr	PC1										-0.004		
	PC2										-0.042		
	PC3										-0.028		
	PC4										-0.036		
	PC5										-0.008		
	PC6										0.005		
	PC7										-0.004		
	PC8										0.006		
LaSt	PC1											0.069	-0.023
	PC2											0.055	0.029
	PC3											0.171	-0.023
	PC4											-0.145	-0.025
	PC5											-0.053	-0.018
	PC6											0.045	-0.002
	PC7											0.048	0.041
	PC8											-0.035	-0.023
U721	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												
U802	PC1										0.069		
	PC2										0.055		
	PC3										0.171		
	PC4										-0.145		
	PC5										-0.053		
	PC6										0.045		
	PC7										0.048		
	PC8										-0.035		

(continued)

(Appendix 4 continued)

PCA on COV.SV

Sp	mesh	32	38	45	51	57	64	70	76	89	102	114	127
FaDa	PC1								-0.012				
	PC2								-0.021				
	PC3								-0.005				
	PC4								-0.023				
	PC5								0.032				
	PC6								0.064				
	PC7								0.024				
	PC8								0.014				
WCra	PC1								0.098				
	PC2								0.054				
	PC3								-0.111				
	PC4								0.006				
	PC5								-0.006				
	PC6								0.000				
	PC7								0.074				
	PC8								0.004				
Sauy	PC1									-0.028			
	PC2									0.040			
	PC3									-0.002			
	PC4									-0.013			
	PC5									0.002			
	PC6									-0.008			
	PC7									0.007			
	PC8									-0.027			
RaTr	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												

(continued)

(Appendix 4 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
MoSc	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												
NPik	PC1							-0.023					
	PC2							0.029					
	PC3							-0.023					
	PC4							-0.025					
	PC5							-0.018					
	PC6							-0.002					
	PC7							0.041					
	PC8							-0.023					

Appendix 5. Loading coefficients for the first eight PC derived from the Principal Component Analysis, on COV/SV with the log transformed relative abundances of species-mesh variables in the West-Central basin.

PCA on COV/SV

Sp mesh		32	38	45	51	57	64	70	76	89	102	114	127
WPer	PC1	0.080	0.094	0.064	0.055	0.048	0.051	0.032	0.036	0.029	0.039	0.036	0.035
	PC2	0.039	0.037	0.031	0.039	0.038	0.037	0.011	0.028	0.020	0.035	0.061	0.025
	PC3	0.103	0.144	0.149	0.134	0.125	0.127	0.103	0.100	0.080	0.086	0.065	0.023
	PC4	0.168	0.156	0.161	0.163	0.158	0.171	0.210	0.176	0.142	0.148	0.052	0.051
	PC5	0.108	0.065	0.052	0.045	0.058	0.062	0.099	0.106	0.090	0.136	0.152	0.034
	PC6	0.008	0.006	-0.002	-0.003	-0.083	-0.103	-0.147	-0.265	-0.228	-0.118	-0.057	-0.007
	PC7	-0.068	-0.026	0.040	0.098	0.120	0.143	0.151	0.147	0.124	0.105	0.022	-0.016
	PC8	-0.151	-0.096	-0.079	-0.023	0.009	0.042	0.053	0.058	-0.002	-0.142	-0.116	-0.019
YPer	PC1	0.064	0.054	0.049	0.032	0.012	0.005	0.007	0.003	0.006	0.011	0.002	0.001
	PC2	0.035	0.033	0.037	0.026	0.015	0.020	0.005	0.016	0.019	0.018	0.001	0.004
	PC3	0.079	0.076	0.093	0.071	0.049	0.033	0.003	0.029	0.014	0.012	0.014	0.016
	PC4	0.118	0.105	0.101	0.068	0.042	0.018	0.035	0.009	-0.007	0.029	0.012	0.029
	PC5	-0.057	-0.071	-0.083	-0.101	-0.062	-0.063	-0.036	-0.008	-0.005	0.022	-0.051	-0.021
	PC6	0.273	0.241	0.254	0.261	0.213	0.183	0.100	0.043	-0.009	0.085	0.050	0.073
	PC7	0.001	0.007	0.007	0.003	0.041	0.040	0.062	0.025	0.025	-0.027	-0.039	0.011
	PC8	-0.038	-0.025	-0.006	0.008	0.021	0.068	0.037	0.004	0.019	-0.001	-0.035	-0.009
FreD	PC1	0.059	0.014	0.004	0.041	0.042	0.015	0.055	0.053	0.057	0.052	0.061	0.080
	PC2	0.129	0.038	0.010	0.071	0.055	0.018	0.067	0.050	0.062	0.063	0.083	0.069
	PC3	-0.022	0.004	0.029	0.113	0.123	0.101	0.075	0.126	0.127	0.117	0.118	0.058
	PC4	0.016	0.019	0.034	-0.006	0.038	0.048	0.072	0.057	0.054	0.094	0.112	0.011
	PC5	-0.024	-0.018	-0.059	-0.138	-0.124	-0.133	-0.107	-0.098	-0.056	-0.048	-0.022	-0.006
	PC6	-0.068	0.026	0.031	0.052	0.004	0.019	-0.004	0.029	-0.039	0.024	-0.037	-0.007
	PC7	-0.023	0.019	-0.001	-0.075	0.005	0.010	0.024	0.001	0.012	0.060	0.047	0.012
	PC8	0.036	0.016	0.001	-0.013	0.037	0.058	0.053	-0.006	0.050	0.005	0.055	0.047
Alew	PC1	0.167	0.184	0.175	0.158	0.128	0.107	0.106	0.171	0.256	0.125	0.076	0.089
	PC2	0.025	0.018	0.033	0.031	0.128	0.237	0.022	0.233	0.106	0.280	0.167	-0.066
	PC3	-0.021	-0.020	-0.022	-0.005	-0.047	-0.072	-0.026	-0.113	-0.105	-0.102	-0.041	-0.004
	PC4	0.020	0.023	0.028	0.038	-0.011	-0.046	0.000	-0.089	-0.056	-0.082	-0.017	0.018
	PC5	-0.180	-0.128	-0.083	0.005	0.019	0.083	0.036	0.073	-0.057	0.081	0.068	0.013
	PC6	-0.066	-0.034	-0.059	-0.036	-0.005	0.026	0.001	0.031	-0.023	0.035	0.016	-0.010
	PC7	-0.125	-0.145	-0.076	-0.127	0.056	0.062	0.098	0.043	-0.008	0.024	0.073	0.098
	PC8	-0.034	-0.101	-0.100	-0.135	-0.097	-0.034	-0.120	0.068	0.032	0.068	-0.088	-0.137

(continued)

(Appendix 5 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
Wall	PC1	0.033	0.011	0.002	0.109	0.002	0.007	-0.001	0.003	-0.004	-0.006	-0.003	-0.003
	PC2	-0.038	0.023	-0.008	0.035	0.002	0.009	0.003	0.007	0.001	0.001	0.003	-0.003
	PC3	0.003	0.104	0.008	0.067	0.024	0.056	0.024	0.045	0.011	0.007	0.012	0.006
	PC4	-0.006	0.066	0.008	-0.055	0.051	0.060	0.057	0.084	0.043	0.038	0.041	0.021
	PC5	0.026	-0.357	0.079	-0.007	0.005	-0.035	0.010	0.012	-0.005	-0.006	0.009	0.009
	PC6	-0.021	-0.147	0.009	0.078	0.079	0.140	0.064	0.112	0.059	-0.028	0.043	0.039
	PC7	-0.078	-0.137	-0.111	0.041	0.049	0.074	0.067	0.058	0.065	0.053	0.094	0.024
	PC8	0.037	0.187	0.032	0.032	0.116	0.114	0.089	0.059	0.096	0.091	0.058	0.081
WSuc	PC1				0.149	0.198	0.011	0.079	0.068	0.037	0.030	0.024	0.017
	PC2				-0.152	-0.207	0.011	0.065	0.036	-0.007	0.027	0.043	0.040
	PC3				-0.010	-0.047	0.163	-0.016	0.139	0.116	0.097	0.150	0.017
	PC4				0.017	-0.029	-0.132	-0.006	0.001	0.054	0.031	0.053	0.038
	PC5				-0.014	-0.035	-0.016	0.061	-0.085	-0.044	-0.040	-0.092	-0.028
	PC6				0.038	-0.015	-0.050	0.079	0.028	-0.009	0.000	-0.180	0.005
	PC7				0.081	0.081	0.031	-0.067	-0.022	-0.046	0.019	0.069	0.009
	PC8				0.051	-0.002	0.086	-0.025	-0.080	0.044	-0.054	-0.017	0.018
RaSm	PC1	-0.001	-0.003	-0.002	0.002	0.003	0.002	0.000	-0.000	-0.002	0.002	0.008	-0.003
	PC2	0.001	-0.001	0.003	0.014	0.010	0.007	0.003	0.004	0.002	0.005	0.011	0.000
	PC3	0.030	0.034	0.048	0.074	0.066	0.043	0.037	0.040	0.026	0.027	0.051	0.003
	PC4	0.006	-0.006	0.035	0.008	0.012	-0.000	0.020	0.001	0.009	-0.005	-0.013	-0.001
	PC5	0.002	0.005	0.037	-0.001	0.013	-0.022	-0.006	0.008	-0.005	-0.006	0.001	-0.014
	PC6	0.054	0.070	0.029	0.148	0.133	0.146	0.164	0.124	0.129	0.136	0.049	0.088
	PC7	0.042	0.035	0.101	0.116	0.095	0.049	0.034	0.044	0.032	0.006	0.045	-0.002
	PC8	-0.051	0.002	0.020	-0.105	-0.096	-0.108	-0.047	-0.088	-0.066	-0.091	-0.127	-0.035
WBas	PC1	0.059	0.081	0.187	0.189	0.054	0.035	0.032	0.049	0.037	0.001	-0.000	
	PC2	-0.044	-0.089	-0.053	0.003	-0.051	-0.026	-0.024	-0.037	0.010	0.004	0.003	
	PC3	-0.003	-0.025	-0.025	-0.055	0.042	0.092	0.044	0.067	0.009	0.013	0.007	
	PC4	0.010	-0.016	0.010	-0.016	0.064	0.055	0.070	0.104	0.020	0.031	0.018	
	PC5	-0.066	-0.026	0.032	-0.029	0.162	0.144	0.094	0.200	0.044	0.037	0.022	
	PC6	0.020	0.021	-0.034	0.006	0.027	0.095	0.043	0.006	-0.108	-0.085	-0.045	
	PC7	-0.053	0.023	-0.063	-0.068	-0.153	-0.185	-0.056	-0.154	0.027	0.035	0.022	
	PC8	-0.057	-0.013	0.043	0.022	0.107	0.176	0.149	0.149	-0.010	-0.020	-0.011	

(continued)

(Appendix 5 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
SiCh	PC1				0.125					0.198			
	PC2				0.280					-0.207			
	PC3				-0.102					-0.047			
	PC4				-0.082					-0.029			
	PC5				0.081					-0.035			
	PC6				0.035					-0.015			
	PC7				0.024					0.081			
	PC8				0.068					-0.002			
SpSh	PC1	0.175	0.148										
	PC2	-0.157	-0.155										
	PC3	0.059	-0.011										
	PC4	0.072	0.032										
	PC5	0.131	0.004										
	PC6	0.059	0.053										
	PC7	-0.252	0.086										
	PC8	-0.180	0.320										
Trpe	PC1	0.095	0.025										
	PC2	0.001	0.015										
	PC3	0.144	0.258										
	PC4	-0.022	-0.205										
	PC5	0.097	0.075										
	PC6	-0.026	-0.073										
	PC7	-0.139	-0.039										
	PC8	-0.154	-0.136										
GSha	PC1								0.249		0.198	0.246	0.129
	PC2								-0.027		-0.207	-0.062	0.261
	PC3								-0.100		-0.047	-0.093	-0.053
	PC4								-0.072		-0.029	-0.066	0.003
	PC5								0.015		-0.035	0.006	-0.151
	PC6								0.006		-0.015	0.002	-0.062
	PC7								0.086		0.081	0.087	-0.164
	PC8								0.037		-0.002	0.030	0.003

(continued)

(Appendix 5 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
ChCa	PC1							0.040	0.107		0.198	-0.001	
	PC2							0.061	0.247		-0.207	0.004	
	PC3							0.061	-0.091		-0.047	-0.002	
	PC4							0.115	-0.073		-0.029	0.000	
	PC5							-0.417	0.093		-0.035	-0.044	
	PC6							-0.151	-0.020		-0.015	-0.030	
	PC7							-0.284	0.032		0.081	-0.024	
	PC8							0.025	0.115		-0.002	0.047	
SBas	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												
RBas	PC1							0.027		0.198			
	PC2							-0.020		-0.207			
	PC3							0.078		-0.047			
	PC4							0.088		-0.029			
	PC5							0.327		-0.035			
	PC6							0.050		-0.015			
	PC7							-0.436		0.081			
	PC8							0.091		-0.002			
Lota	PC1		-0.002		-0.003	-0.004			-0.005	-0.002	-0.006	-0.005	-0.006
	PC2		-0.001		-0.003	-0.004			-0.005	-0.004	-0.004	-0.007	-0.008
	PC3		-0.001		-0.011	-0.014			-0.020	-0.015	-0.016	-0.017	-0.019
	PC4		-0.000		-0.014	-0.020			-0.027	-0.014	-0.017	-0.010	-0.029
	PC5		-0.002		0.001	0.001			-0.000	-0.019	-0.001	0.010	0.017
	PC6		0.043		-0.015	-0.013			-0.013	0.032	-0.002	-0.023	0.015
	PC7		0.026		-0.012	-0.019			-0.025	-0.034	-0.013	-0.004	-0.050
	PC8		0.001		0.003	-0.002			0.001	-0.031	-0.001	0.011	-0.016

(continued)

(Appendix 5 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
NRSu	PC1									0.009	0.147	0.019	
	PC2									0.002	-0.127	0.015	
	PC3									0.040	0.187	0.281	
	PC4									0.048	-0.160	-0.324	
	PC5									0.043	0.189	0.021	
	PC6									0.012	0.019	-0.003	
	PC7									-0.037	-0.176	0.063	
	PC8									0.114	0.074	0.033	
LaWh	PC1								-0.001	-0.001	-0.001	-0.002	-0.002
	PC2								0.000	0.001	0.001	0.003	-0.000
	PC3								0.004	0.005	0.005	0.012	-0.001
	PC4								0.020	0.016	0.016	0.031	0.003
	PC5								0.021	-0.003	-0.003	0.008	-0.007
	PC6								-0.010	0.041	0.041	0.007	0.031
	PC7								0.038	0.034	0.034	0.070	0.018
	PC8								-0.018	0.015	0.015	0.004	0.021
Coho	PC1			0.011	0.019	0.016							
	PC2			-0.012	0.015	0.019							
	PC3			0.032	0.281	0.264							
	PC4			0.074	-0.324	-0.243							
	PC5			0.040	0.021	-0.092							
	PC6			0.091	-0.003	-0.083							
	PC7			0.041	0.063	0.003							
	PC8			0.454	0.033	0.061							
Ston	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												

(continued)

(Appendix 5 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
EShi	PC1	0.005											
	PC2	0.010											
	PC3	0.032											
	PC4	0.060											
	PC5	-0.028											
	PC6	-0.068											
	PC7	0.037											
	PC8	0.028											
Quil	PC1							-0.003		0.011			
	PC2							-0.002		0.019			
	PC3							-0.006		0.017			
	PC4							-0.005		0.033			
	PC5							-0.000		0.029			
	PC6							0.012		-0.004			
	PC7							0.018		0.072			
	PC8							0.009		-0.149			
BBul	PC1						0.019			-0.001			
	PC2						0.015			0.001			
	PC3						0.281			0.005			
	PC4						-0.324			0.022			
	PC5						0.021			0 029			
	PC6						-0.003			-0.072			
	PC7						0.063			0.033			
	PC8						0.033			-0.008			
Bowf	PC1		-0.001										
	PC2		0.000										
	PC3		0.003										
	PC4		-0.000										
	PC5		0.005										
	PC6		-0.066										
	PC7		-0.008										
	PC8		-0.009										

(continued)

(Appendix 5 continued)

PCA on COV/SV

Sp	mesh	32	38	45	51	57	64	70	76	89	102	114	127
GoPe	PC1									0.125			
	PC2									0.280			
	PC3									-0.102			
	PC4									-0.082			
	PC5									0.081			
	PC6									0.035			
	PC7									0.024			
	PC8									0.068			
TaMa	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												
YBul	PC1					0.003							
	PC2					0.009							
	PC3					0.038							
	PC4					0.051							
	PC5					-0.049							
	PC6					-0.113							
	PC7					0.085							
	PC8					0.051							
Carp	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												

(continued)

(Appendix 5 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
LaTr	PC1							0.003				-0.004	
	PC2							0.002				-0.004	
	PC3							0.022				-0.013	
	PC4							0.034				-0.019	
	PC5							-0.012				-0.000	
	PC6							0.046				-0.007	
	PC7							-0.022				-0.018	
	PC8							-0.101				0.000	
LaSt	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												
U721	PC1										0.001		
	PC2										0.003		
	PC3										0.017		
	PC4										0.038		
	PC5										0.027		
	PC6										0.017		
	PC7										0.054		
	PC8										-0.041		
U802	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												

(continued)

(Appendix 5 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
FaDa	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												
WCra	PC1							0.198					
	PC2							-0.207					
	PC3							-0.047					
	PC4							-0.029					
	PC5							-0.035					
	PC6							-0.015					
	PC7							0.081					
	PC8							-0.002					
Saug	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												
RaTr	PC1								0.002				
	PC2								0.019				
	PC3								-0.009				
	PC4								-0.006				
	PC5								0.046				
	PC6								-0.093				
	PC7								0.022				
	PC8								0.109				

(continued)

(Appendix 5 continued)

PCA on COV/SV

Sp\mesh		32	38	45	51	57	64	70	76	89	102	114	127
MoSc	PC1								0.005				
	PC2								0.010				
	PC3								0.042				
	PC4								0.047				
	PC5								-0.022				
	PC6								-0.005				
	PC7								0.015				
	PC8								-0.026				
NPik	PC1												
	PC2												
	PC3												
	PC4												
	PC5												
	PC6												
	PC7												
	PC8												

Appendix 6. Covariance of the catch between consecutive years for the eight main species.

white perch			1987-88	1988-89	1989-90
Number of paired stations			5	2	2
Basin	stratum	mesh			
Western	0-10m	32	-1.4237	-0.3805	0.0000
Western	0-10m	38	-0.5721	0.0000	0.0000
Western	0-10m	45	-0.4698	0.0000	-0.5017
Western	0-10m	51	-0.5682	0.0265	-0.8633
Western	0-10m	57	-1.1747	-0.6634	-0.7395
Western	0-10m	64	-4.3707	-1.2221	-1.3353
Western	0-10m	70	0.0416	2.7489	-0.7982
Western	0-10m	76	-2.6518	1.2745	-0.6471
Western	0-10m	89	-1.5940	3.0754	-0.6330
Western	0-10m	102	-0.4058	-0.2401	-0.7415
Western	0-10m	114	-0.3270	0.0000	0.2401
Western	0-10m	127	0.0000	----	----
Number of paired stations			3	4	4
Western	10-15m	32	0.4278	0.0622	-0.1035
Western	10-15m	38	0.3755	0.2013	-0.0635
Western	10-15m	45	0.3041	-0.1300	-0.1797
Western	10-15m	51	0.8774	-0.1616	0.0470
Western	10-15m	57	0.9401	-0.1886	0.0274
Western	10-15m	64	1.0492	-0.1958	-0.0525
Western	10-15m	70	1.8541	-0.3252	0.2737
Western	10-15m	76	1.3345	-0.7278	0.3751
Western	10-15m	89	0.2205	-1.5013	1.1163
Western	10-15m	102	0.0000	-0.1006	0.0000
Western	10-15m	114	-0.0192	0.0574	0.0000
Western	10-15m	127	-0.0800	0.0800	0.0000

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

(Appendix 6 continued)

white perch			1987-88	1988-89	1989-90
Number of paired stations			6	7	6
Basin	stratum	mesh			
West-Central	0-10m	32	-0.2406	1.8718	0.0441
West-Central	0-10m	38	-0.1562	1.9428	0.4137
West-Central	0-10m	45	-0.1403	1.0433	-0.3098
West-Central	0-10m	51	-0.1413	1.2116	0.2537
West-Central	0-10m	57	-0.3857	1.3714	0.0889
West-Central	0-10m	64	-0.8412	0.3799	0.2628
West-Central	0-10m	70	-0.1927	1.2282	0.5224
West-Central	0-10m	76	-0.7438	0.1946	-0.0041
West-Central	0-10m	89	-0.0519	0.3615	0.2175
West-Central	0-10m	102	0.1037	0.0089	0.0546
West-Central	0-10m	114	-0.1115	0.2725	0.0000
West-Central	0-10m	127	-0.1242	0.0229	-0.0160
Number of paired stations			1	1	0
West-Central	10-15m	all	....	....	....
Number of paired stations			6	1	3
West-Central	15m +	32	0.0000	....	----
West-Central	15m +	38	0.0000	....	----
West-Central	15m +	45	0.1872	....	-0.1169
West-Central	15m +	51	-0.2190	....	-0.6921
West-Central	15m +	57	0.1236	....	-0.1779
West-Central	15m +	64	-0.0630	....	-0.2943
West-Central	15m +	70	0.0311	....	-0.2234
West-Central	15m +	76	----	....	0.5546
West-Central	15m +	89	----	....	0.0000
West-Central	15m +	102	----	....	----
West-Central	15m +	114	----	....	----
West-Central	15m +	127	-0.0254	....	----

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

4 OF/DE 4

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0 4.5 5.0 5.6

(Appendix 6 continued)

yellow perch			1987-88	1988-89	1989-90
Number of paired stations			5	2	2
Basin	stratum	mesh			
Western	0-10m	32	1.5393	-0.6490	0.3808
Western	0-10m	38	0.3495	-0.8177	2.3640
Western	0-10m	45	0.1013	-0.2530	2.1692
Western	0-10m	51	0.4121	-0.0782	3.0241
Western	0-10m	57	0.2634	0.0343	1.7683
Western	0-10m	64	0.8884	0.0870	0.7204
Western	0-10m	70	0.3223	0.4654	0.0000
Western	0-10m	76	0.0008	0.3174	-0.3808
Western	0-10m	89	0.0000	----	----
Western	0-10m	102	0.0720	0.0000	-0.2401
Western	0-10m	114	----	----	----
Western	0-10m	127	----	----	----
Number of paired stations			3	4	4
Western	10-15m	32	0.3221	0.1363	0.4835
Western	10-15m	38	0.4824	0.1227	0.4645
Western	10-15m	45	0.3902	0.0672	1.1506
Western	10-15m	51	0.4047	-0.0239	0.0165
Western	10-15m	57	0.5654	-0.0294	0.1456
Western	10-15m	64	0.1269	-0.0126	-0.1012
Western	10-15m	70	-0.3202	0.1172	0.0841
Western	10-15m	76	-0.3202	-0.1269	-0.3876
Western	10-15m	89	-0.0800	-0.0400	-0.2401
Western	10-15m	102	----	----	----
Western	10-15m	114	0.0000	0.0000	----
Western	10-15m	127	----	----	----

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

(Appendix 6 continued)

yellow perch			1987-88	1988-89	1989-90
Number of paired stations			6	7	6
Basin	stratum	mesh			
West-Central	0-10m	32	0.3848	-0.3880	0.2160
West-Central	0-10m	38	-0.0294	-0.6800	0.5246
West-Central	0-10m	45	0.2618	-0.3030	0.1426
West-Central	0-10m	51	-0.0860	0.1555	-0.3883
West-Central	0-10m	57	-0.2395	0.2496	0.0103
West-Central	0-10m	64	-2.1305	-0.3728	0.1684
West-Central	0-10m	70	-0.0899	-0.0909	-0.0799
West-Central	0-10m	76	-0.1336	-0.2168	-0.2770
West-Central	0-10m	89	-0.0044	-0.0650	-0.0508
West-Central	0-10m	102	-0.0160	-0.0229	----
West-Central	0-10m	114	----	----	----
West-Central	0-10m	127	----	----	----
Number of paired stations			1	1	0
West-Centr-l	10-15m	all	....	....	....
Number of paired stations			6	1	3
West-Central	15m +	32	0.6933	....	----
West-Central	15m +	38	0.7550	....	0.0000
West-Central	15m +	45	0.8061	....	----
West-Central	15m +	51	0.6430	....	0.8649
West-Central	15m +	57	0.8014	....	1.0399
West-Central	15m +	64	0.5722	....	0.4140
West-Central	15m +	70	0.2344	....	0.3311
West-Central	15m +	76	0.0171	....	0.2870
West-Central	15m +	89	----	....	0.5894
West-Central	15m +	102	0.0000	....	0.0000
West-Central	15m +	114	----	....	----
West-Central	15m +	127	----	....	----

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

(Appendix 6 continued)

freshwater drum			1987-88	1988-89	1989-90
Number of paired stations			5	2	2
Basin	stratum	mesh			
Western	0-10m	32	0.0000	----	----
Western	0-10m	38	----	----	0.0000
Western	0-10m	45	0.0240	----	----
Western	0-10m	51	0.9060	-1.1117	0.0000
Western	0-10m	57	0.9307	-0.1883	0.5575
Western	0-10m	64	0.4119	0.0000	0.0000
Western	0-10m	70	0.3670	0.0000	0.0000
Western	0-10m	76	-0.0349	-1.2384	0.0000
Western	0-10m	89	-0.4104	-0.2905	0.7204
Western	0-10m	102	0.4647	0.0000	0.0000
Western	0-10m	114	-0.1409	1.2655	0.0000
Western	0-10m	127	-0.1482	0.0995	0.0000
Number of paired stations			3	4	4
Western	10-15m	32	0.0800	----	----
Western	10-15m	38	----	----	----
Western	10-15m	45	----	0.0000	0.0000
Western	10-15m	51	1.3575	0.3925	-0.1124
Western	10-15m	57	1.2490	0.1600	-0.0129
Western	10-15m	64	0.2296	-0.2237	-0.8549
Western	10-15m	70	-0.3528	0.6219	-2.2880
Western	10-15m	76	0.3962	0.7203	0.1261
Western	10-15m	89	-0.2070	0.7591	-1.6038
Western	10-15m	102	-0.3533	0.5944	-0.3048
Western	10-15m	114	0.1601	0.1860	0.0930
Western	10-15m	127	----	0.2387	-0.0331

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

(Appendix 6 continued)

freshwater drum			1987-88	1988-89	1989-90
Number of paired stations			6	7	6
Basin	stratum	mesh			
West-Central	0-10m	32	----	----	-0.0160
West-Central	0-10m	38	----	----	----
West-Central	0-10m	45	----	----	----
West-Central	0-10m	51	-0.2608	0.2136	0.0000
West-Central	0-10m	57	-0.1690	0.2444	0.3244
West-Central	0-10m	64	-0.7395	0.1475	-0.0260
West-Central	0-10m	70	0.1127	0.1845	-0.3902
West-Central	0-10m	76	-0.7531	0.0284	0.0965
West-Central	0-10m	89	-0.8133	-0.2485	-0.1113
West-Central	0-10m	102	-0.3302	-0.0856	0.2205
West-Central	0-10m	114	-0.4198	0.0498	-0.1353
West-Central	0-10m	127	0.2724	0.1228	0.0000
Number of paired stations			1	1	0
West-Central	10-15m	all	....	....	....
Number of paired stations			6	1	3
West-Central	15m +	32	----	....	----
West-Central	15m +	38	----	....	----
West-Central	15m +	45	----	....	----
West-Central	15m +	51	0.0000	....	----
West-Central	15m +	57	-0.0508	....	----
West-Central	15m +	64	0.0695	....	-0.1269
West-Central	15m +	70	0.0188	....	0.4026
West-Central	15m +	76	-0.0188	....	0.2916
West-Central	15m +	89	0.0000	....	0.0000
West-Central	15m +	102	0.2031	....	0.0000
West-Central	15m +	114	----	....	----
West-Central	15m +	127	----	....	----

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

(Appendix 6 continued)

alewife			1987-88	1988-89	1989-90
Number of paired stations			5	2	2
Basin	stratum	mesh			
Western	0-10m	32	0.4053	----	----
Western	0-10m	38	0.4283	0.0000	----
Western	0-10m	45	0.5119	0.0000	----
Western	0-10m	51	0.4744	----	----
Western	0-10m	57	----	----	----
Western	0-10m	64	----	----	----
Western	0-10m	70	----	----	----
Western	0-10m	76	----	----	----
Western	0-10m	89	----	----	----
Western	0-10m	102	----	----	----
Western	0-10m	114	----	----	----
Western	0-10m	127	----	----	----
Number of paired stations			3	4	4
Western	10-15m	32	----	----	----
Western	10-15m	38	0.0000	----	----
Western	10-15m	45	----	0.0000	----
Western	10-15m	51	----	----	----
Western	10-15m	57	----	----	----
Western	10-15m	64	----	----	----
Western	10-15m	70	----	----	----
Western	10-15m	76	----	----	----
Western	10-15m	89	----	----	----
Western	10-15m	102	----	----	----
Western	10-15m	114	----	----	----
Western	10-15m	127	----	----	----

---- One of the two years has no variance.

.... The two years have no variance.

(continued)

(Appendix 6 continued)

alewife			1987-88	1988-89	1989-90
Number of paired stations			6	7	6
Basin	stratum	mesh			
West-Central	0-10m	32	-0.0546	`.0653	----
West-Central	0-10m	38	-0.1990	----	----
West-Central	0-10m	45	-0.3134	----	----
West-Central	0-10m	51	-0.0549	----	----
West-Central	0-10m	57	----	----	----
West-Central	0-10m	64	----	----	----
West-Central	0-10m	70	----	----	----
West-Central	0-10m	76	----	----	----
West-Central	0-10m	89	----	----	----
West-Central	0-10m	102	----	----	----
West-Central	0-10m	114	----	----	----
West-Central	0-10m	127	----	----	----
Number of paired stations			1	1	0
West-Central	10-15m	all	....	....	....
Number of paired stations			6	1	3
West-Central	15m +	32	----	....	----
West-Central	15m +	38	----	....	----
West-Central	15m +	45	----	....	----
West-Central	15m +	51	----	....	----
West-Central	15m +	57	----	....	----
West-Central	15m +	64	----	....	----
West-Central	15m +	70	----	....	----
West-Central	15m +	76	----	....	----
West-Central	15m +	89	----	....	----
West-Central	15m +	102	----	....	----
West-Central	15m +	114	----	....	----
West-Central	15m +	127	----	....	----

---- One of the two years has no variance.

.... The two years have no variance.

(continued)

(Appendix 6 continued)

walleye			1987-88	1988-89	1989-90
Number of paired stations			5	2	2
Basin	stratum	mesh			
Western	0-10m	32	0.1441	----	----
Western	0-10m	38	-0.1523	0.0000	0.0000
Western	0-10m	45	0.1446	0.0000	0.2401
Western	0-10m	51	0.2003	0.0000	0.2401
Western	0-10m	57	0.1627	0.0000	0.0000
Western	0-10m	64	-0.1458	0.0000	0.0000
Western	0-10m	70	0.0371	-0.6393	-0.3396
Western	0-10m	76	-0.1723	0.2231	0.9847
Western	0-10m	89	-0.0306	0.4802	0.2802
Western	0-10m	102	0.2844	-0.3808	0.0000
Western	0-10m	114	0.0000	0.0000	0.0000
Western	0-10m	127	-0.1143	0.0000	0.0000
Number of paired stations			3	4	4
Western	10-15m	32	----	----	----
Western	10-15m	38	----	----	----
Western	10-15m	45	0.0000	0.1201	0.0000
Western	10-15m	51	0.1343	-0.0492	-0.0800
Western	10-15m	57	----	-0.1071	-0.2401
Western	10-15m	64	0.3470	----	----
Western	10-15m	70	0.3868	0.1337	0.0491
Western	10-15m	76	0.2870	0.1094	-0.1357
Western	10-15m	89	0.0800	0.0000	0.1132
Western	10-15m	102	0.0000	0.0575	0.0820
Western	10-15m	114	----	0.0166	0.0910
Western	10-15m	127	----	-0.1201	-0.1944

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

(Appendix 6 continued)

walleye			1987-88	1988-89	1989-90
Number of paired stations			6	7	6
Basin	stratum	mesh			
West-Central	0-10m	32	0.0000	0.0000	----
West-Central	0-10m	38	----	----	----
West-Central	0-10m	45	----	----	----
West-Central	0-10m	51	-0.1754	----	----
West-Central	0-10m	57	----	-0.1049	----
West-Central	0-10m	64	-0.0414	0.2033	0.0000
West-Central	0-10m	70	----	0.0390	0.0480
West-Central	0-10m	76	----	-0.0865	-0.0843
West-Central	0-10m	89	----	0.0572	-0.0414
West-Central	0-10m	102	-0.0160	0.0343	----
West-Central	0-10m	114	----	-0.0591	0.0000
West-Central	0-10m	127	----	-0.0820	0.0000
Number of paired stations			1	1	0
West-Central	10-15m	all	....	....	....
Number of paired stations			6	1	3
West-Central	15m +	32	----	....	----
West-Central	15m +	38	----	....	----
West-Central	15m +	45	----	....	----
West-Central	15m +	51	----	....	----
West-Central	15m +	57	----	....	----
West-Central	15m +	64	----	....	----
West-Central	15m +	70	-0.0668	....	0.0000
West-Central	15m +	76	0.0000	....	----
West-Central	15m +	89	----	....	0.0000
West-Central	15m +	102	-0.0348	....	0.0000
West-Central	15m +	114	----	....	0.0000
West-Central	15m +	127	----	....	0.0000

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

(Appendix 6 continued)

white sucker			1987-88	1988-89	1989-90
Number of paired stations			5	2	2
Basin	stratum	mesh			
Western	0-10m	32	----	----	----
Western	0-10m	38	-0.1523	0.0000	0.0000
Western	0-10m	45	0.1446	0.0000	0.2401
Western	0-10m	51	0.0000	0.0000	0.0000
Western	0-10m	57	0.0539	-0.2401	0.3808
Western	0-10m	64	0.0701	0.0000	0.0000
Western	0-10m	70	0.1358	0.0000	0.0000
Western	0-10m	76	0.4287	0.4370	0.1407
Western	0-10m	89	-0.0664	-0.8841	0.0000
Western	0-10m	102	-0.0003	-2.1799	0.3077
Western	0-10m	114	-0.2268	-1.1816	0.2401
Western	0-10m	127	----	0.0000	----
Number of paired stations			3	4	4
Western	10-15m	32	----	----	----
Western	10-15m	38	----	----	----
Western	10-15m	45	0.0000	0.1201	0.0000
Western	10-15m	51	----	0.0000	----
Western	10-15m	57	----	----	0.0000
Western	10-15m	64	0.0000	0.0000	0.0000
Western	10-15m	70	0.0000	-0.1269	0.0000
Western	10-15m	76	0.1058	-0.1035	-0.0800
Western	10-15m	89	0.0000	-0.2910	-0.5842
Western	10-15m	102	0.0000	0.1237	-0.2074
Western	10-15m	114	0.0000	-0.0137	-0.2048
Western	10-15m	127	----	0.0000	0.0000

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

(Appendix 6 continued)

white sucker			1987-88	1988-89	1989-90
Number of paired stations			6	7	6
Basin	stratum	mesh			
West-Central	0-10m	32	----	----	----
West-Central	0-10m	38	----	----	----
West-Central	0-10m	45	----	----	----
West-Central	0-10m	51	0.0000	----	----
West-Central	0-10m	57	----	----	----
West-Central	0-10m	64	0.0000	0.0000	----
West-Central	0-10m	70	0.0000	----	----
West-Central	0-10m	76	0.0613	-0.0650	0.0000
West-Central	0-10m	89	0.0323	0.0311	0.0000
West-Central	0-10m	102	-0.0860	0.0383	-0.0640
West-Central	0-10m	114	0.0762	-0.0773	-0.0988
West-Central	0-10m	127	0.0000	0.0000	-0.0320
Number of paired stations			1	1	0
West-Central	10-15m	all	....	....	....
Number of paired stations			6	1	3
West-Central	15m +	32	----	....	----
West-Central	15m +	38	----	....	----
West-Central	15m +	45	----	....	----
West-Central	15m +	51	----	....	----
West-Central	15m +	57	----	....	----
West-Central	15m +	64	----	....	----
West-Central	15m +	70	----	....	----
West-Central	15m +	76	----	....	----
West-Central	15m +	89	----	....	----
West-Central	15m +	102	-0.0320	....	----
West-Central	15m +	114	----	....	----
West-Central	15m +	127	----	....	----

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

(Appendix 6 continued)

rainbow smelt			1987-88	1988-89	1989-90
Number of paired stations			5	2	2
Basin	stratum	mesh			
Western	0-'0m	32	----	----	----
Western	0-10m	38	----	0.0000	0.0000
Western	0-10m	45	----	----	----
Western	0-10m	51	----	----	----
Western	0-10m	57	----	----	----
Western	0-10m	64	----	----	----
Western	0-10m	70	----	----	0.0000
Western	0-10m	76	----	----	----
Western	0-10m	89	----	----	----
Western	0-10m	102	----	----	----
Western	0-10m	114	----	----	----
Western	0-10m	127	----	----	----
Number of paired stations			3	4	4
Western	10-15m	32	----	----	-0.0400
Western	10-15m	38	----	----	----
Western	10-15m	45	----	----	----
Western	10-15m	51	----	----	----
Western	10-15m	57	0.0000	----	----
Western	10-15m	64	0.0000	0.0000	-0.0800
Western	10-15m	70	----	----	0.0000
Western	10-15m	76	----	----	----
Western	10-15m	89	----	----	----
Western	10-15m	102	----	----	----
Western	10-15m	114	----	----	----
Western	10-15m	127	----	----	----

---- One of the two years has no variance.
.... The two years have no variance.

(ccntinued)

(Appendix 6 continued)

rainbow smelt			1987-88	1988-89	1989-90
Number of paired stations			6	7	6
Basin	stratum	mesh			
West-Central	0-10m	32	-0.0403	-0.0181	0.0640
West-Central	0-10m	38	-0.0960	----	----
West-Central	0-10m	45	-0.0828	----	----
West-Central	0-10m	51	-0.1164	----	----
West-Central	0-10m	57	-0.2964	----	----
West-Central	0-10m	64	-0.1908	-0.0410	----
West-Central	0-10m	70	-0.0828	----	----
West-Central	0-10m	76	-0.1015	----	----
West-Central	0-10m	89	-0.0657	----	----
West-Central	0-10m	102	0.0000	----	----
West-Central	0-10m	114	----	----	----
West-Central	0-10m	127	0.0000	----	----
Number of paired stations			1	1	0
West-Central	10-15m	all	....	....	....
Number of paired stations			6	1	3
West-Central	15m +	32	0.0049	....	----
West-Central	15m +	38	0.0133	....	----
West-Central	15m +	45	-0.0094	....	0.0000
West-Central	15m +	51	0.2299	....	----
West-Central	15m +	57	0.3773	....	----
West-Central	15m +	64	-0.2355	....	----
West-Central	15m +	70	-0.0446	....	----
West-Central	15m +	76	-0.1500	....	0.0000
West-Central	15m +	89	-0.2127	....	----
West-Central	15m +	102	0.1096	....	----
West-Central	15m +	114	-0.0160	....	----
West-Central	15m +	127	0.0000	....	----

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

(Appendix 6 continued)

white bass			1987-88	1988-89	1989-90
Number of paired stations			5	2	2
Basin	stratum	mesh			
Western	0-10m	32	----	----	----
W stern	0-10m	38	----	----	----
Western	0-10m	45	----	----	----
Western	0-10m	51	0.0000	0.0000	0.0000
Western	0-10m	57	----	0.0000	----
Western	0-10m	64	0.2656	-0.2401	0.0000
Western	0-10m	70	----	0.0000	0.0000
Western	0-10m	76	0.3386	0.0000	0.2401
Western	0-10m	89	-0.0762	0.0000	0.0000
Western	0-10m	102	----	----	0.0000
Western	0-10m	114	0.0000	0.0000	0.0000
Western	0-10m	127	----	----	----
Number of paired stations			3	4	4
Western	10-15m	32	0.0000	----	----
Western	10-15m	38	----	----	----
Western	10-15m	45	0.0000	----	----
Western	10-15m	51	0.0000	----	----
Western	10-15m	57	----	0.0000	----
Western	10-15m	64	----	----	----
Western	10-15m	70	----	----	----
Western	10-15m	76	----	-0.2053	0.0000
Western	10-15m	89	----	0.1904	----
Western	10-15m	102	----	0.0000	----
Western	10-15m	114	----	----	----
Western	10-15m	127	----	----	----

---- One of the two years has no variance.
.... The two years have no variance.

(continued)

(Appendix 6 continued)

white bass			1987-88	1988-89	1989-90
Number of paired stations			6	7	6
Basin	stratum	mesh			
West-Central	0-10m	32	----	----	----
West-Central	0-10m	38	----	----	----
West-Central	0-10m	45	0.0000	----	----
West-Central	0-10m	51	0.0000	----	----
West-Central	0-10m	57	0.0000	----	----
West-Central	0-10m	64	-0.0414	-0.1098	----
West-Central	0-10m	70	0.0000	----	----
West-Central	0-10m	76	0.0000	0.2252	0.0000
West-Central	0-10m	89	-0.0160	-0.0181	-0.0508
West-Central	0-10m	102	----	----	-0.0320
West-Central	0-10m	114	----	----	----
West-Central	0-10m	127	----	----	----
Number of paired stations			1	1	0
West-Central	10-15m	all	....	....	....
Number of paired stations			6	1	3
West-Central	15m +	32	----	....	----
West-Central	15m +	38	----	....	----
West-Central	15m +	45	----	....	----
West-Central	15m +	51	----	....	----
West-Central	15m +	57	----	....	----
West-Central	15m +	64	----	....	----
West-Central	15m +	70	----	....	----
West-Central	15m +	76	----	....	0.0000
West-Central	15m +	89	----	....	----
West-Central	15m +	102	----	....	----
West-Central	15m +	114	----	....	----
West-Central	15m +	127	----	....	----

---- One of the two years has no variance.
.... The two years have no variance.

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